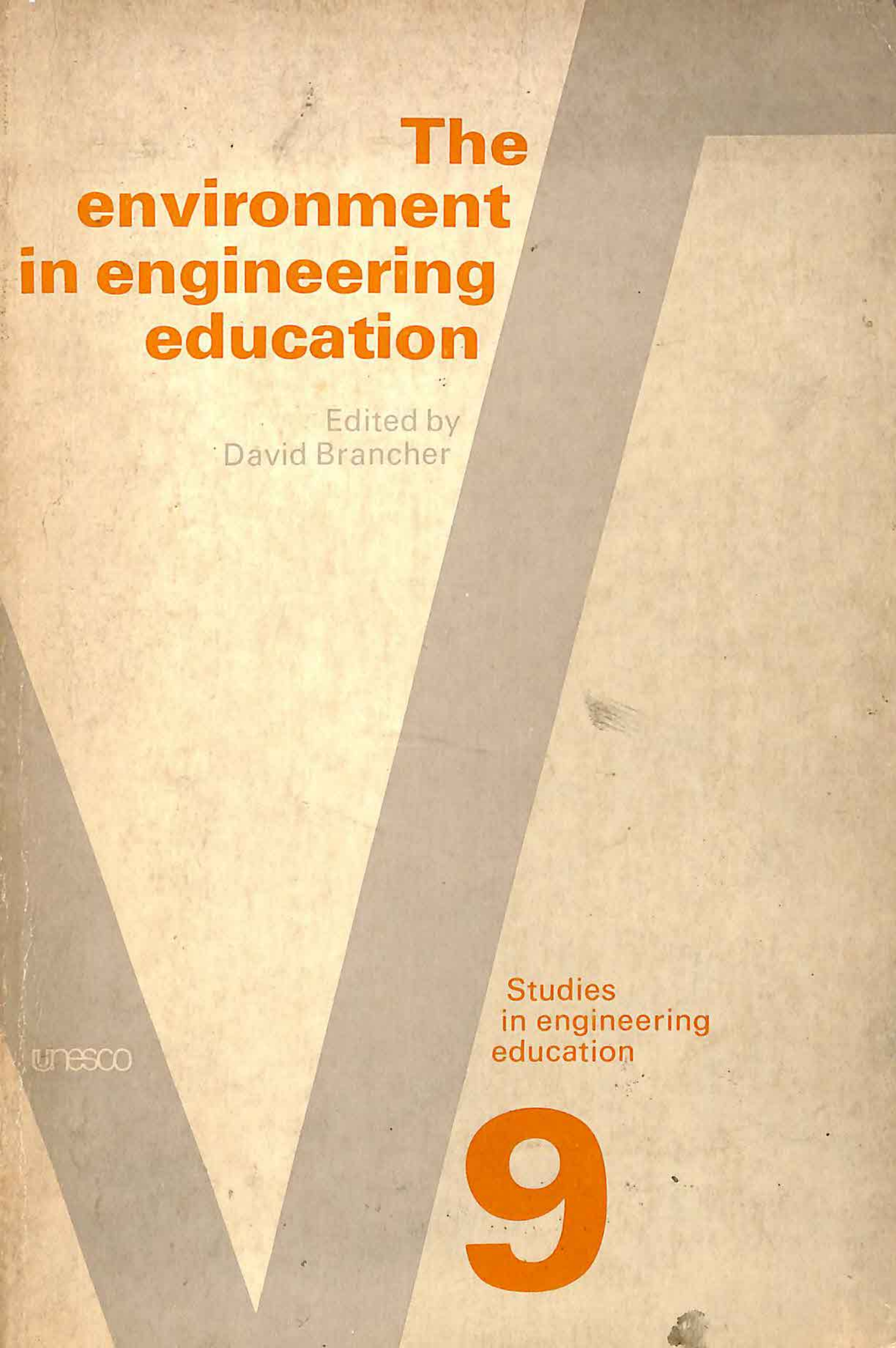

The environment in engineering education

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Edited by David Brancher

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Preface

The Environment in Engineering Education responds to the need – felt equally in the industrialized and developing world – for broadening and renewing the educational experiences offered to men and women preparing for the engineering professions. It deals with what is perhaps the major aspect of their responsibility to society. As the ninth in the series 'Studies in Engineering Education' it reinforces and exemplifies the approach made in the second, *Social Sciences and Humanities in Engineering Education.* It shows how the ability to meet the environmental challenge depends on a thorough grounding in relevant aspects of the socio-humanistic disciplines. And it emphasizes that these insights must be integrated with technique and the real world of engineering, as part of the educational process, if they are to be of professional value.

In the present volume four basic aspects are discussed by the authors: the engineering of the work environment; the choice and implementation of appropriate technology; the education of specialists in environmental engineering; the aims of academic organization and the strategies which can be employed by decision-takers in higher education. The problems approached by the authors have been identified as matters of high priority by the International Working Group on the Environmental Education of Engineers. The group, created to advise the Director-General of Unesco, held its first session in Paris in 1975, its second in Caracas, Venezuela, in 1977, and its third in Paris in 1979.

Unesco is indebted to Dr David Brancher, editor of this work and author of the sections on academic organization and appropriate technology, and to the other authors, Professor Gideon Gerhardsson, Dr Hassan El-Baroudi, Dr Dev R. Sachdev and Professor Adel Hamouda. It expresses its thanks also to George McRobie, who convened the meeting of advisers in appropriate technology, and to Professor Richard Booth and Dr Dennis Else, who contributed the material for the case-study on the work environment.

All authors have expressed facts and ideas independency of the Organization and their opinions are not necessarily those of Unesco.

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Introduction

David Brancher

Any discussion of the environmental education of engineers is likely to be disrupted by an awkward question: What does environment mean? If engineers are supposed to be taught about it, what they should do with it and what they should protect it from, then we need to know what it really is.

This is a fair question – and a revealing one. Trying to answer it reveals that things and processes which represent environment to one engineer are part of the job itself to another kind of engineer. For example, a chemical engineer discharging waste material into a river (with or without damage – it makes no difference) is having an effect on the environment. Environmental education for him or her means learning something about the ecology of rivers.

To the water-resources engineer dealing with the river, the same discharge involves the setting and enforcing of effluent standards, monitoring results, maintaining summer flows and so on. It is the very centre of the job. But take the same water engineer to the national park where the river begins and you may find that he or she also needs environmental education. The damming of rivers, the raising of lake levels, and the construction of roads and buildings can have a profound effect on the quality of the landscape and its recreational potential. This field of environmental education, in turn, we find to be the central responsibility of yet another kind of engineer – the landscape architect. The boundary between professional function and environment is clearly relative. Where it seems to lie depends on what kind of engineer you are.

We can find a similar relativity along the dimension of time. Twenty or thirty years ago, in most developed countries, 'the work environment' was a concept of limited meaning for most mechanical and production engineers. In so far as problems were recognized they were seen as belonging to specialists in industrial medicine and a few other subjects. Now it is generally understood that the industrial work environment, at least in many respects, is something to be engineered; to be studied, created or improved, and monitored, largely by engineers. The boundary between the engineer's role and the setting of that role has shifted. It has moved under the pressures of public concern and a greater awareness within industry of what constitutes a well-engineered work process.

We can see, then, that the definition of environment and environmental education is hampered by relativity. Where the environment begins is relative to engineering specialization and is changing in time. Perhaps more precision might be gained by a consideration of pollution, for surely the control and elimination of pollution are primary aims of environmentalism.

Pollution can be objective, as in the case of toxic chemicals. It can also be subjective, as in the case of landscape degradation. And it can be both objective and subjective, as in the problem of noise. Pollution can have direct effects on human beings, as in the case of drinking-water supply. Its effects can be indirect, where it is affecting fish stocks. It can be more or less dependent of ecosystems and it can make itself felt through symbiotic or parasitic interactions which only an expert can comprehend.

Pollution can be totally unacceptable and call for elimination at all costs, or it can require economic judgement in which the costs of this or that level of treatment are balanced against the gains and losses which would result from using money (i.e. resources) in some other way. The idea of pollution as the presence of matter or energy where it is unwanted, at first glance so simple, turns out to be of little use in definition, in environmental education as in engineering itself.

Nor is the idea of resource depletion any more helpful. One reason is that resources exist only to the extent that they are recognized. A national park has been depleted if bad management has caused it to provide less of the wilderness experience for which it was originally designated. The centre of a historic town can lose its capacity to offer the architectural experience for which it might have been conserved. In both cases, and of course in a multitude of others, the losses are subjective but nevertheless real and important.

But even physical resources, unquestionably objective and tangible, depend on perception. Their depletion is real to the extent that we know we have uses for them. It is less real to the extent that we know that substitution or the elimination of need can be arranged at reasonable cost (and 'reasonable cost' is itself a matter of perception). Resources, then, may be tangible, intangible, aesthetic and 'economic'. They appear and disappear in the light of what we know and what we care about. They are cultural constructs.

If we find such difficulty in defining environment, how can we handle environmental education? Chasing this elusive and amorphous spirit through the forest, we may perhaps wonder if the pursuit of definition is worth while. It certainly is not worth while in the sense that we will ever be able to say that environmental education is concerned with this and not with that. An absolute definition will always escape us, and for a very important reason.

Engineering is about creating wealth – that is, physical, social, and mental well-being – in the real world. It takes things from this real world, the environment of engineering, and puts them back with added value. Without this addition of value, engineering has no meaning. Engineering for the sake of engineering is not engineering at all; it never was. In this sense all engineering is 'about the environment'.

A systems view

Has the word 'environment' any use for us at all, then, in this time of debate and criticism? It has, in only one respect, which we take from the field of systems theory. For engineering – whether we regard it as a group of people, as a cluster of institutions, or as a body of knowledge and skills' – is itself a system. And, like all systems it has an environment – other people and their values and goals; other institutions; other knowledge and activities. It tries to be open; to take information from the changing environment. It tries to redefine its environment by extending its field of information and control. And where it cannot maintain its existing goals engineering must adapt by finding new goals and by reorganizing its internal structure to match them.

All three of these characteristics can be observed in engineering. And it is only by taking a systems view that we can find a concept of environment and environmental education which holds its validity through time and across the many specialisms and responsibilities in the engineering profession. The paradox is that by defining the environmental education of engineers in this way we are ruling out the permanent definition of engineering itself.

The major implications are matters of vision. In the future, if engineers are to meet the environmental challenge, they will need to look: (a) outwards as well as inwards; (b) to future generations as well as this; (c) to less obvious effects as well as the obvious; (d) to intangibles as well as to tangibles; (e) to immeasurables as well as to measurables; and (f) to true wealth as well as to narrow commercial gain.

The logic of this Introduction, as so far developed, sets the slim volume of papers an impossible task. It is tempting, as always, to try to condense and summarize all that might be said; to reduce the field of knowledge (in so far as the authors may comprehend it) to a series of lists and prescriptions. This would be a mistake, carrying with it the certainty of trivialization. It seems better to be selective and to focus more narrowly, using two criteria which appear apropriate. First, it is important that the subjects should have contemporary international significance, having regard to the role of Unesco in bringing together the developed and developing nations. Second, because many readers will be senior decision-takers in higher education, it seems appropriate that the papers emphasize the strategic matters which are important in developing environmental education and the schools which offer it.

Earlier, while attempting to resolve the conceptual problem, we noted some systems-characteristics which can be observed in the engineering profession, as it adapts to new circumstances. We can use these characteristics now in introducing the four papers.

Wider boundaries

Ten or fifteen years ago it would have been unthinkable to include the concept of the work environment in a collection of papers on the environmental education of engineers. More recently, however, a new awareness has shown itself in government, among industrialists and trade-union leaders, and in the general public. It shows itself in the recognition that the industrial work environment can have chemical and physical characteristics which are injurious to health in both the long and the short term.

At the same time, and under the influence of bodies such as the World Health Organization and the International Labour Organisation, the idea of health has itself taken on a wider meaning. This meaning, perhaps better expressed as 'wealth' in the original definition, expresses a concern for the well-being of the worker as a whole person. It sees the working individual as not only breathing and hearing and manipulating and moving, but also as someone looking for purpose in work, and the chance of self-fulfilment.

In some ways the industrial work environment has improved in the one and a half centuries since the earlier-developing nations began large-scale industrialization. Although much remains to be done, and new processes pose new risks, a proportion of industrial work is now cleaner, less toxic, quieter and safer. Where this improvement has occured, much of the credit belongs to engineers.

But comparisons must be made, not with historic situations, but with current expectations. The industrial worker of a century ago lived in a tight, self-contained, and inward-looking community of people who could imagine no other form of employment (unless it was the even harsher life of the agricultural worker of those times). His leisure hours were few, and he lacked the money to make full use of them anyway.

Today the picture is different. Even in the later-developing countries most industrial workers have radios and some have television. The young have opportunities to travel and the transistor has united them in an international youth-culture whose values the older generation is slow to comprehend. At all ages the industrial worker of today has expectations and aspirations which were limited to only a few, even ten or twenty years ago.

When these aspirations are not met; when management cannot see even that they exist; when work is felt to be cramping and monotonous; when the physical environment is unhealthy and potentially dangerous, we have the conditions in which workers can be alienated from their work, their employers, and even from each other. Of course, it is the task of managers and trade-union leaders to avoid the development of such a situation and to deal with it where it already exists. But the key role lies with the expert specialist – engineer, industrial physician, ergonomist and so on, in giving advice to both sides so that they can become one side. In his chapter, Gideon Gerhardsson reviews the expertise necessary in understanding and improving the work environment.

The role of the engineer in this important and critical activity varies from one industry to another and from one field of knowledge to another. In some situations the engineer needs to know, indeed should know, as much as anyone. In others the centre of expertise lies with another profession, but the engineer needs to appreciate the problem and what can be done about it. It is unrealistic to think that engineering students can and should be required to learn to an even depth throughout the field of the work environment. Not only would this be wasteful overall, it would inevitably mean superficial learning where high competence was required.

With this in mind, Professor Gehardsson uses two categories or levels in describing areas of knowledge: 'appreciation', where a broad understanding is sufficient; and 'working', where the engineer has the responsibility for effective action. More important still, the chapter recognizes that, because of the wide span covered by engineering, the definition of the two levels of expertise must vary from one branch of engineering to another.

As elsewhere in the environmental education of engineers, motivation can present a problem. It is not that engineering students are not capable of being interested in environmental matters. It is, rather, that their perception of engineering and the engineer's role tends to be limited to a narrow stereotype. The challenge to teachers is that this perception has to be extended so that students recognize the breadth of their future responsibilities. The paper suggests some ways in which the educational problem can be handled and emphasizes, in particular, the special contribution which can be made by case studies.

New goals

Earlier in this Introduction we underlined the difficulty in fixing the limits of environmental education, particularly where engineers are concerned. If indeed all engineering is 'about the environment' then it follows that it should be appropriate to the environment in which it is applied. And, to a student or engineer who has been educated in the systems approach, 'environment' means not only the biological context. It means the totality of tangible and intangible surroundings with which the man-made system interacts.

Like many truisms this assertion is both trivial and profound. It is the trivial aspect which causes some engineers to dismiss the concept of 'appropriate technology' as something so obvious as to be almost without significance. Such a reaction is perhaps understandable among those who have never been to a region where technology has failed to close the gap between nutrition and starvation, between wide-scale disease and health, between shelter and homelessness; who have not seen the many failures of technology in economic and social development.

And it is the profound implication of the appropriate-technology concept which leads others to be offended by it. Such people have been known to ask if anyone is suggesting that their particular technological expertise is *in*appropriate. Most colleagues are too polite to respond to such a challenge and this leads to the subject being kept below the surface of discussion.

In education the concept of appropriate technology can appear nebulous. Let us consider an idealized school of engineering where students are exercised in both the 'hard' and 'soft' problems of economic and social development; where they are educated in the relevant social sciences; where the staff are personally committed to the humane use of technology; and so on. Even in such a school it is difficult to give an answer to an apparently simple question like 'Do you cover appropriate technology in your course?' It is rather like asking a medical school whether it does the human side of medicine.

To raise the topic of appropriate technology is to beg a large number of questions. And it is right to do so. It would be tragic, in the real sense of the word, to let engineering education end this decade without a reconsideration of the problems and issues of a world in which there is too much hunger, disease, homelessness and unemployment; in which technologies have been devised and transferred which have too often turned out to be inappropriate, sometimes at vast cost in resources, time, disappointment and even suffering.

The successful use of technology for economic and social development is a much more complex matter than is implied by the now largely discredited notion of 'technology transfer'. The perception and acceptance of technological opportunities depends on factors which may be cultural, social, political and even religious. The grasping of such opportunities may depend on economic considerations such as the availability of physical resources and financial capital, and the size, skills and motivation of the intended work-force. The viability of a new technology beyond the short term may depend on the capacity of the economic and social infrastructure (for example in matters of education and training) and on the resilience of the biological environment and its ecology. Above all the long-term stability of the development will reflect the extent to which it meets the fundamental economic and social needs of the mass of the people, as distinct from the aspirations of a political or bureaucratic faction.

It is, however, a profound mistake to assume that appropriate technology is a concept or set of ideas to be considered only in the developing countries. Nothing could be further from the minds of those who helped prepare the second paper in this volume. The affluent countries of the world do not generally have poverty of the kind which scars so many countries still at an early stage of development. But they do have intractable problems, for example in their cities, in their natural environment, in structural unemployment. Many of these problems have been created by the indiscriminate and ill-considered use of technology. It is because of this that one can find today, probably in every technologically advanced country, innovations in engineering education which reflect a concern that such mistakes be avoided in future.

Such innovations do not, of course, always appear under the banner of appropriate technology. Neither do they appear necessarily as complete degree programmes or even as self-contained courses. They may arise, for example, as lecture-series on technology and urban problems, on job-creation, or on alternative energy sources; they may appear as options which enable a minority of students to meet some of their worries sabout the future of Western-style technology; very often they emerge in the selection of design projects, supervised by forward-looking teachers. And such projects may be wider-ranging than has been normal in the past; in many schools of engineering there is a growing use of 'socio-technical' projects of the kind developed through the 'general Education in Engineering' project in the United Kingdom and as pioneered in several schools in the United States.

Re-structuring

The adjective 'civil' is used in several language-groups to designate the engineer whose concern is with the construction of roads, dams, bridges, canals, pipelines and framed structures of many kinds. Few lay persons realize that the term dates from the time when the professional centre of engineering was military. As a comparable level of status came to be accorded to non-military purposes, the practitioners were called 'civil engineers' to make this clear. Even today in some countries, the term covers the whole field of non-military engineering at the professional level. In other countries, the new technologies of the nineteenth and twentieth centuries are reflected in a profusion of titles and professional bodies. Professional structure, in other words, has been determined by historical circumstances.

For many reasons, it is easier to found a new professional body than it is to rationalize the pattern that already exists. It may even be easier to start a new degree programme or university department than it is to reorganize the courses and schools which are already in operation. But sometimes the accidents of history leave too heavy a burden or block too many opportunities for professional development and wider service to the community. This is the situation today in environmental engineering, according to El-Baroudi, Sachdev and Hamouda. These authors, from the viewpoint of high-level experience in both developing and developed countries, see the need for restructuring in practice and in education, to reflect the emerging needs of clients.

Here, then, is another example of the adaptation of a profession to a changed working environment. Some professional and academic bodies are autonomous. Others are closely controlled by government. But in either case it is the conceptualization of past, present and future which facilitates change. Indeed, it is only by modelling that we can handle the goals and constraints which face us in any complex situation. El-Baroudi, Sachdev and Hamouda offer a model in the hope that readers will test its validity against their own experience in education and professional practice.

Openness

Armed with some of the ideas and suggestions of the first three papers, the academic administrator faces those decisions for which he or she has the ultimate responsibility. In any school new subjects can be ordained to replace older ones; new methods can be prescribed to supersede those which have been relatively unsuccessful; new teachers can be appointed and gain influence. But the guarantee that such changes will be made as soon as they are needed; that they will be improvements and not merely alterations; that they will be assimilated and become fruitful, cannot come from the wisdom or strength of the senior administrator at any point in the school's history. This is too much to expect and far too much to rely on. The ultimate safeguard lies in the character of the school itself; the existence of a collective learning culture (among faculty but involving students and their learning also); the capacity of the system to remain open.

Most administrators seem to assume that the structure and staffing of a school should be decided, once and for all, when it is known what is to be taught and researched in the school. Structure is seen, in other words, as an event. The fourth paper in the set takes, in contrast, a dynamic view of academic organization. Structure and educational content are seen as interactive and mutually creative.

Obviously, some early decisions must be taken on organization. These decisions should, of course, leave opportunities for revision. They should also, however, set out deliberately to provide the conditions in which new teaching needs can be met with new teaching arrangements; in which the results of research can immediately influence educational content; and, in which the thrust of content is a reflection of shared environmental concern.

The idea of dynamic structure is not new, and many efforts and experiments have been made. The final paper review some of the schemes which have been used and criticizes them as vehicles for environmental education. The author also suggests some criteria for the evaluation of academic structures in general, and for assessing the appointment and performance of staff members. He singles out for special mention the distinctive needs of the non-engineer teacher in a school whose main function is engineering education.

Work sciences and the engineer

Gideon Gerhardsson

> *Occupational health should aim at: the promotion and maintenance of the highest degree of physical, mental and social well-being of workers in all occupations; the prevention among workers of departures from health caused by their working conditions; the protection of workers in their employment from risks resulting from factors adverse to health; the placing and maintenance of the worker in an occupational environment adapted to his physiological and psychological equipment and to summarize: the adaptation of work to man and of each man to his job. – Joint ILO/WHO Committee on Occupational Health (1950)*[1]

Introduction

Technical universities have many clients – students, employers, professional associations, the work force, the public at large. Each group of clients may at one time or another demand a somewhat different set of subjects, a different order of emphasis. As if these incipient conflicts were not enough, the engineering educator faces problems of change and expansion. Subjects develop or decline in importance. New subjects appear and within each subject knowledge expands and new insights are achieved.

Coupled with conflict and change is the problem of interrelation. The systems approach, throughout engineering and management, has forced us to recognize that factors impinge one on another, and that any system must be understood as a whole if we are to achieve the results we want. In the education of engineers the integration of knowledge is not only difficult; it makes a further demand on the time of teacher and student.

Although many people pay lip-service to the need for broadly educated engineers, it is often the non-technical subjects which run the greatest risk of being squeezed out of the curriculum. And although engineers have learned to apply the systems philosophy in describing, designing and controlling physical systems, they persist in making an instrumental approach to questions of the working environment and job design. It is not that they are inhumane, it is simply that they see the worker as a component. If this component causes or suffers problems – absenteeism, ill-health, accidents, boredom, for example – it is other kinds of experts who should intervene.

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[1] WHO Technical Report Series No. 66, Geneva, 1952, p. 4.

The engineer tends to be concerned with efficiency and optimization. In his or her technical education these concepts can be narrowly defined. It is not surprising that reductionism has been carried over into the human elements of socio-technical systems, with results which have sometimes been merely temporary, but sometimes have come to assume the dimensions of social disaster.

But things are changing in the domain of the engineer, and nowhere faster than in the field of the work environment. Accidents and industrial disease are now seen more clearly to be avoidable. Boredom and anomy are recognized as not the worker's fault. Work is understood to be a social activity in which wages, although important, are not the sole reward. In meeting these and other problems the work sciences have much to offer.

They may be referred to thus, in the plural. But to treat them only as a collection of separate biological and social-science subjects would be educationally and professionally damaging. In no part of engineering education is an integrated approach more necessary. The intention of this chapter is to show not only what needs to be taught, but how the curriculum can bring together the available knowledge and lead towards, even if it cannot guarantee, a comprehension of all that we mean by the work environment. In the difficult social and economic conditions which lie ahead, this comprehension among engineers will be of crucial importance.

DEVELOPMENT

Improvements in the standard of living depend mainly on production potential. Efforts to promote growth are often based on a short-term approach which offers little scope for long-term planning. New sources of energy, new materials and new work processes are constantly appearing, and largely replacing the old ones. The lines of development we choose to follow must be based both on conditions as they are now and on how we want them to be in the future. This big question is how to use available resources in the most expedient way. Human resources are the most valuable of all.

Anxieties over the work environment are by no means restricted to countries with a high economic standard of living. The surge of industrialization is headlong all over the world. Famine and poverty are being fought with methods of production that are largely transmitted from the already highly industrialized countries, but which must be applied in societies where the conditions differ in whole or in part from those where

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these methods were gradually evolved. Besides, this process is proceeding at a pace which allows even less time for adjustment to the conditions under which individuals are supposed to live and work.

In the developing countries by far the most urgent problem for many years will be to create as much employment as possible with a minimum of capital investment. While the present level of investment is boosting labour demand at an impressive rate, the new technologies are also increasing unemployment, particularly among the poorly educated. It is the young who are hardest hit by rising unemployment. Even those with a college education seem to be disappointed in their search for work, and many who have a good theoretical education but no practical experience have to compete for poorly paid jobs. This youthful but maladjusted élite can become a dangerous element in the political and ideological spheres.

Programmes for achieving and maintaining a good standard of health among the working population, and for creating an acceptable workplace environment, must take into account the level of technological development of the country concerned. Courses in the work sciences also should reflect such levels of development, while taking into account the standards which may later be achieved and demanded by workers.

THE INTERDISCIPLINARY CONCEPT

Engineering is concerned with production and construction, and its academic base lies in the natural sciences, technology, industrial organization and economics. The workers in engineering are the subject of the behavioural and social sciences. The work sciences are intermediate between these two domains and are therefore inherently interdisciplinary. Here are some of their major ingredients (see also Fig. 1):

Accidents and safety. These deal with accident causes, accident patterns, proneness, random chance, individual factors, technical factors, safety statistics, studies of incidents, legislation.

Occupational medicine and occupational hygiene. These reflect the medical impact of the environment. They draw on toxicology, physiology, ecology and technology. They study how humans are affected by chemical and physical factors and devise technical measures for analysing these factors and eliminating unwanted ones (ergonomic criteria).

Work physiology. This is based on anatomy and physiology. It deals with the relationship between the human body and its performance. It also studies how performance is affected by environmental factors like vibration or micro-climate at the place work.

Technical psychology. This is based on applied psychology. It studies the practical design of technical systems. It adapts them to the way human beings function. For example, control panels must be designed to match human perception, sensory and physiological reactions.

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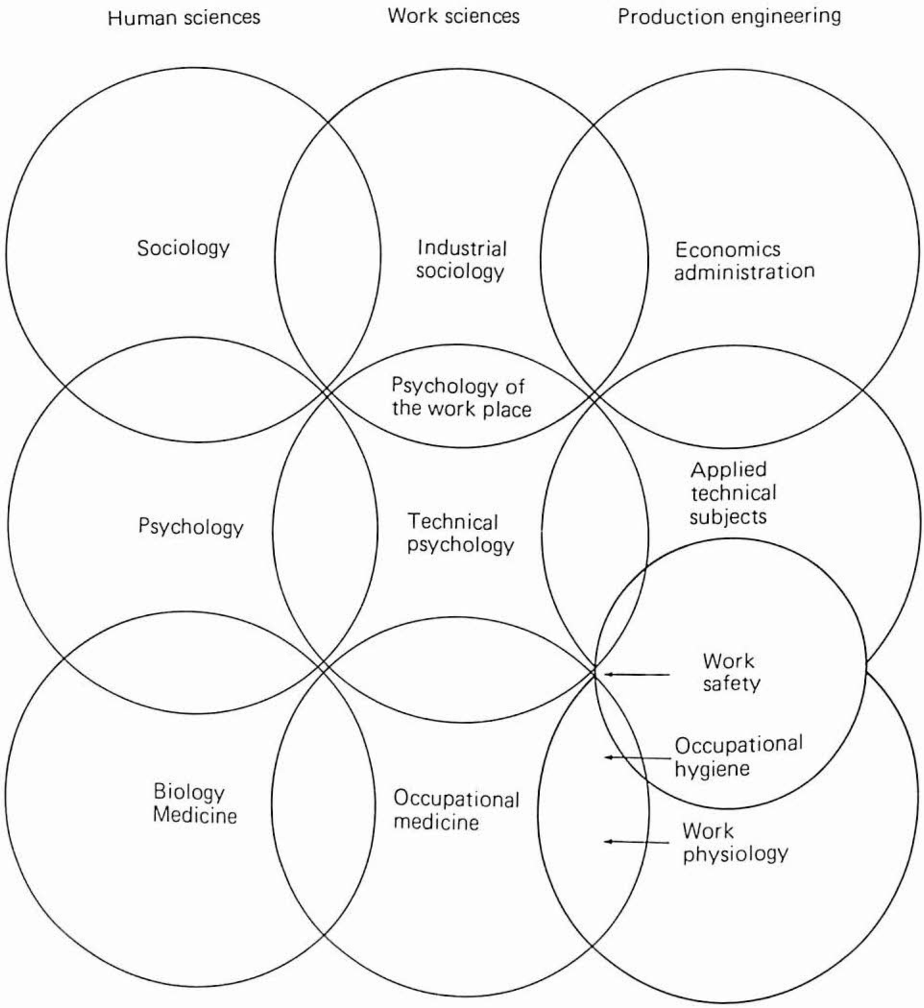

Fig. 1. Work sciences bridge the gaps between human sciences and production engineering.

Psychology and the work-place. This deals with the relations between individuals and groups. The enterprise or place of work is regarded as a system that must be continously updated to improve the psychological climate, focusing on the needs and wishes of the individual human being. It is also concerned with how conditions at the work-place affect life outside the work-place and vice versa.

Industrial sociology. This studies the way an enterprise is organized. The various functions are continuously analysed and modified. The aim is to maintain efficient production while increasing the satisfaction of the people who work there. Industrial sociology focuses on the needs of the enterprise as a technical and social system.

Systems ergonomics. This seeks to develop methods for a broad analysis of the interaction between man, machine and environment. We return to this point in the section 'Work Sciences and the Environment' below.

The human worker

BIOLOGICAL LIMITATIONS

It can be said that man has to adapt himself to three different time scales: the biological, the technological and the social. A satisfactory simultaneous adjustment to these three chronologies is not always easy to accomplish. Population increase, urbanization and industrialization create problems which are highly diversified and vary with the level of technical development.

Although man's life expectancy has increased, his basic biological characteristics have not changed appreciably since history began. His inborn performance capacity is believed to be the same as it was many thousands of years ago. Cellular change and individual reactions are also the same. The human brain is trained more today than before, but has roughly the same capacity. But because our chances of reaching a ripe old age are greater, many new problems arise, such as adapting to occupational and social change.

These problems are intensified for the individual, because the common chronological pattern for life functions is a continuous rise to a maximum which persists for a short period of time, after which a more or less slow decline commences. In modern industrial production, man's biological limitations are accentuated after only twenty to twenty-five years of his life.

TECHNOLOGICAL CHANGES

For thousands of years little technological progress was made. The technological revolution came with the steam engine in the eighteenth century and with the breakthrough of electricity and the internal combustion engine in the nineteenth century. Now, in the atomic, plastics and space age, it is scarcely possible any more to keep up with technological progress except by extreme specialization within increasingly narrow fields. Conditions are changing at a steadily accelerating rate, and technological change is having deeper and deeper ramifications in most areas of our lives. Industrial processes increasingly require a young labour force, excluding the elderly and the handicapped. This trend must be reversed in order to prevent even greater portions of the elderly and the handicapped from being excluded from productive work.

SOCIAL CHANGES

The social time-scale falls between the biological and the technological scales. Prior to the industrial revolution slightly more than 200 years ago, man lived in a static world in which the conditions of live were regarded as being unchanging. The major social changes came in connection with the expansion of technology. Changes in society do not occur as rapidly as changes in technology. In the future, technological change will be of decisive importance for economic and social conditions in the world. New sources of energy, new materials and new processes will replace old ones. The society, factory, farm and office of tomorrow will therefore bear little resemblance to those of today, either in ways of working or in social attitudes to work.

THE PURPOSE OF THE WORK SCIENCES

Current research in the field of work sciences is concerned with integrating these three patterns of change – the biological, technological and social – with all of the limitations and possibilities this entails. The goal of the research is to describe and interpret the consequences of the new demands and stresses imposed by the working environment on the individual, and to attempt to meet the demands made by the individual on his working environment. This is done by means of applied research and also by drawing on the findings of research and experience in specialist fields. The aim is the synthesis which best serves industry, the individual and society, and leads to a further and general increase in real living standards.

Classical research in the field of work sciences was concerned mainly with clinical aspects on treatment of accidents caused by machines and various ways to prevent direct injuries on the job. The next phase concentrated on preventing occupational diseases as well, and eventually unnecessary physical deterioration. The third and current phase is aimed at creating optimal working conditions. In order to achieve this goal, the industrial environment must be viewed in its entirety and as a part of society as a whole. Problems such as the right man in the right place, job satisfaction and the interaction between on-the-job and off-the-job factors then gain an entirely different dimension.

HIERARCHY OF NEEDS

Social changes have a great impact on human needs. There are different theories concerning the structure of human needs and their changes with time. A differentiation is made between primary inborn needs for such basic things as food, drink, sleep, sex, etc., and secondary acquired needs, such as needs arising from habits and social group affiliation–e.g. needs for alcohol and nicotine. In many cases, the hierarchy of needs described by Maslow provides a useful model. This model can be illustrated in the form of a number of levels. We must first satisfy the lower need level before we can seriously become interested in the next level. Maslow ranks human needs in the following order of priority:

1. *Physiological needs.* Those needs which must be satisfied first are those which concern physical survival, i.e. food, drink and shelter. As long as these basic needs cannot be satisfied, it is likely that the individual's main interest will be directed towards this level. Other levels are not as interesting. A need level which has already been satisfied, on the other hand, carries little motivation in the future.
2. *Security.* When our basic physiological needs have been satisfied, our needs for security and safety come to the fore. Here we refer to freedom from fear of physical danger and from fear that our basic physiological needs will not be satisfied.
3. *Social affiliation.* When our physiological needs and our need for security have been satisfied, our need for social affiliation and companionship becomes a dominant factor in the hierarchy of needs. As a social animal, man needs to feel an affinity with other human beings. At this level, the individual strives for meaningful relationships with other people.
4. *Esteem.* When the need for social affiliation has been satisfied, the individual is no longer satisfied with being a member of the group – he also needs esteem, both self-esteem and the esteem of others. Many social problems can be seen to have their root in people's frustration in their attempt to satisfy these needs for esteem.
5. *Self-actualization.* When this level has been satisfied, self-actualization becomes the dominant interest. Self-actualization means developing one's innate capacities to their full potential; being all that one can be.

The relationship between motivation and behaviour is complicated, but Maslow's simple model appears to agree well with reality. An individual's social motivation and social needs are developed by constant interaction with other people. This interaction includes comparisons with other people. In the occupational sphere, it is necessary to take into consideration both the horizontal-need structure, which includes job demands on behalf of disadvantaged groups of people at a given point in time, and the vertical-need structure, which has to do with the change of needs with time, and the level of development of each occupational group concerned. Such comparisons are made both in order to establish priorities and to foresee the continuous change in levels of ambition, i.e. the increase of individual demands. However, these demands must be considered in relation to the realistic possibilities of their being met. Different alternatives must be open to discussion. If such matters are not included in their education, engineers encounter considerable difficulties in their professional lives later on.

THE HUMAN WORKER

In order to approach an optimal interaction between individuals and a technological system, we must possess knowledge not only of the technological system, but also (and, indeed, especially) knowledge of man himself and his fundamental characteristics as a living organism. The living cell provides the necessary pre-conditions for reproduction, nutrient assimilation, metabolism, energy cycles, growth, excretion and sensitivity to stimulation. Knowledge of the skeletal system, joints, musculature, etc., is necessary in order to evaluate work-loads and patterns of movement. Metabolism is dependent upon the digestive organs, respiratory organs, excretory organs, circulatory organs, and the internal secretory apparatus. The nervous system with the sensory organs forms the basis for all learning and virtually all reactions.

All of these organs function in a manner which can easily be disturbed. The locomotory apparatus, for example, is controlled by the nervous system. Certain internal secretory disorders cause characteristic changes in the locomotory apparatus, etc. An elementary knowledge of the mechanisms which determine the capabilities and limitations of the human body in different work situations is an absolute prerequisite for an understanding of the criteria which must later be dealt with in practical situations.

As we saw from Maslow's model we can have different levels of ambition in our attempts at occupational adjustment. The primary level involves maintaining human safety and health. A higher level involves the satisfaction of various subjective human needs.

Adapting work to the worker

HAZARDS AND HAZARD ANALYSIS

Workers may be exposed to many different hazards. In conventional treatments of this subject in engineering schools, a description of hazards is often limited to different types of accidents, injuries, etc., and the statistical distribution of such events among different industries and activities. It is, however, important that the student also be familiar with how hazards are perceived and experienced, the psychology of errors and the difference between voluntary and involuntary hazards. In many situations, people compound involuntary hazards with voluntary ones: in some cases, the latter are thousands of times greater than the former.

One must also differentiate between hazards which concern individuals and hazards which affect entire groups of people.

In a hazard analysis, an attempt is made to establish the potential errors or malfunctions which can cause bodily injury or damage to machinery or equipment. The pathways between such events and the gravity and extent of possible outcomes must be traced. The probability of outcomes must also be established with as much certainty as possible. On the basis of hazard analysis, proposals are then made for reducing risks. This may be accomplished by reducing the chances of error or malfunction, or by limiting their consequences, or by a combination of both means. The automation of processes or parts of processes, the proper training of personnel, etc., are among the ways of reducing this probability. Consequences can be limited by means of various safety arrangements or by locating dangerous operations in isolated places.

Hazard analysis should be carried out at the earliest stages of plant or construction design. This strategic approach is not only to limit the presence of hazards when the working environment is finally created. It is also a matter of saving money. Measures which might be carried out at the level of 5–10 per cent of overall cost in the early phases of design may require an expenditure of from 30 to 40 per cent if correction is to be carried out later. It is important to remember also that the analysis of hazards must cover those which may arise during construction and plant installation. This does not imply that analysis need be carried out in great detail. Its sophistication should be appropriate to the scale of the project. A modest investment of time and thought can provide an important general picture of the influential hazard situations and help to decide where and when more detailed studies may be needed.

In a general hazard analysis, an attempt is made to list all characteristic hazards and describe them in quantitative terms. The following categories may be used: degree of deviation from the normal course of events; releasing factor; effects; and consequences. The hazard is described both by the probability of the event and by the consequences. A general analysis of a department may include the following: (a) department layout; (b) process and flow scheme; (c) work-places and production places; (d) control, supervision and safety equipment; (e) transportation of materials and products; and (f) environmental conditions. On the basis of this overall picture hazards are identified and chances and consequences are quantified. Remedial steps may seek to reduce both chance and consequence; in some cases action may be directed at one or other. Recommendations may affect processes, flows and layout; production plant specifications and safety devices; work-place location and lighting; training; emergency services; inspection and reporting; notices and instructions.

SOCIAL CONTACTS

People have the need for social contact, but also sometimes for privacy. Indeed, it has been said that willingness to engage is related to freedom to withdraw. Both needs, and the opportunity of choice between them should be reflected in the design and layout of work-places.

Work-benches, work-tables and machines can be placed opposite each other. Break areas should be provided near the work-place. The offices can also be located adjacent to the work-places. This latter arrangement facilitates contacts between employees on the shop floor and employees in the office, for example between managers and workshop supervisors.

CO-OPERATION

Workers' tasks should be drawn up in such a way that co-operation is easy where required, and encouraged where it is likely to enrich the social reward which workers obtain from their jobs. Team-working should often be encouraged and its introduction is related to the question of job enlargement dealt with below.

MACHINE DEPENDENCE

This arises where an individual is tied to his equipment so that he cannot leave his work-place. It appears to be more significant than automation, as such, in causing job dissatisfaction. Machine dependence can be reduced by the introduction of buffer stores (see below), which enable individuals to leave their work-places for short spells. Automatic machine-feed from hoppers and the like also increase freedom of movement. In general, the smaller the manual part of the cycle time, the greater is the degree of freedom experienced by the worker.

JOB ENLARGEMENT

Jobs can be made more interesting by introducing different side- or sub-tasks in addition to the main task. Examples of such related tasks are maintenance operations, for example, of tools and other equipment, production-preparatory functions, the moving of materials and products, store-keeping, inspections, etc. Such duties raise the individual's level of independence and responsibility and reduce the risk of interruptions.

A greater degree of responsibility for product quality and the working environment increases the individual worker's satisfaction with, and commitment to, his job. Maintenance duties can be introduced both by giving production personnel individual maintenance duties and by organizing the work into production groups. The maintenance duties which are primarily suitable for integration in production are day-to-day maintenance and repairs of equipment and tools, lubrication, inspection of vital machine parts and wear, weekly services and cleaning. Examples of production-preparatory duties are setting-up and changing of tools and machines, adjustments, etc.

If the production personnel are made responsible for moving materials and products between and within small production units, buffer stores can be inserted between different work operations. The fact that the production workers themselves manage the supply store results in smaller storage units, permits the use of joint work-place stores and improves the level of utilization and accessibility. If quality control is partially or completely turned over to the production personnel it becomes easier to organize inspection operations and often possible to improve product quality. Job enlargement has frequently been achieved within the building industry by training workers in different occupational fields. Welders, for example, can often be trained for other metal-working tasks. In some countries and situations, however, trade unions may resist this.

Jobs can be enlarged vertically by adding responsibilities and powers. Supervisors, production engineers and others can gradually be given more and more duties to perform. Work cycles can be extended by integrating sequential production operations or similar work duties. The opportunities for this depend on the production technique which is chosen. Continuous supervision of an automated process is, for example, difficult to combine with job enlargement. By means of automation, monotonous or dirty jobs can be eliminated and better combinations of work duties can be created. Computers also can eliminate tedious routine tasks, leaving human beings free for innovation and the use of judgement. But the effect of automation and computers in reducing employment is fast becoming a major issue in developed countries – an issue beyond the scope of this chapter.

BREAKS, RESTING TIME AND SHIFT WORK

The scheduling of breaks and rests is an important question. Many functions in the human body are adjusted to a rhythmic alternation between exertion and recovery, between work and rest. This applies, for example, to the muscles, and not least, to the heart. Frequent overtime work has been shown to reduce performance per hour and to increase absenteeism due to illness and accidents.

The scientific literature contains a number of illuminating studies concerning working hours, rests and breaks, and their influence on production. Energy requirements have been calculated for most types of work which demand muscular exertion. The necessary length and frequency of breaks can be determined on the basis of the physical work-load and its variations. The pace at which the job should be performed, the demands which are made on concentration, psychomotor activities, energy load, sensory organs, etc., can also be determined. Increased mechanization and automation and rising investments in expensive equipment increase the need for shift work. Certain manufacturing processes – for example, within the chemical, paper, and steel industries – cannot be interrupted without great difficulties, cost or delay. But a person's daily rhythm is dependent upon physiological and psychological factors. It takes time to alter human habits.

Shift work is not suitable for people who cannot adapt themselves satisfactorily to the changing shift schedule. A number of different shift systems have been tested. A basic rule for all forms of shift work is that night shifts should be followed by sufficiently long leave and that opportunities should be provided for undisturbed sleep.

JOB EVALUATION

Job evaluation is aimed at measuring the demands which are imposed by the job. There are different methods for measuring skills, performance and other variables. Experience has shown that even imperfect job evaluation systems are better than none at all. Evaluating the amount of work involved in a job permits greater fairness in establishing wage differentials. The subject is probably outside the scope of undergraduate courses.

SYSTEMS ANALYSIS

When human beings are incorporated in a technological system, efforts should be made to provide for an organized variety of work tasks. Human beings interact with technical components in different ways. From the viewpoint of work sciences it is often necessary to divide technological development into different stages. A common example is stages of mechanization.

An early stage of mechanization is characterized by the fact that the individual's job is still relatively varied and permits him to control his own work situation. At this industrial level, the combination of man/tool dominates. Early forms of handicraft belong to this category. Total output efficiency is relatively limited and is determined mainly by the individual person and his own abilities. The combination is based on a simple organization.

The second stage is the man/machine combination. In this intermediate level, the individual is controlled by his machine or by mechanical routines. His work is determined to a great extent by persons other than himself, such as machine designers, layout men, work-study engineers, etc. The work consists of repetitive movements in relatively fixed sequences. Working posture, control devices, etc., determine his mode of working and he is locked in a time framework with little variation. Output is high and exceeds the individual's own capacity many times over. Organization, however, is still simple at this stage – for example, in the combination of man and forestry machine.

The next stage is man/machine systems which contain more than one person working together in a complex manner. At this level of mechanization, the worker is once again liberated from his machine. The machine assumes many of the repetitive control and feed operations. The worker gains greater freedom in choosing his own pattern of movement and physical activities. However, higher demands are made on the person's sensory organs and alertness and on his ability to make quick judgements and independent decisions.

Further development at this level leads to the individual being more bound to the machinery, but seldom having to interfere in the production process. Physical demands are low. Psychological demands are also relatively modest as far as the continuous work process is concerned, but higher demands are made on independent action when something unexpected happens. The psychological requirements are a high level of alertness and preparedness and an ability to act quickly and correctly in abnormal situations. Individuals become more isolated and the emergence of difficult, unexpected situations can increase stress.

Work sciences and the curriculum

CURRICULAR PROBLEMS

Elsewhere in this work the point is made that mere lists of knowledge provide the teacher only with a syllabus. To create a curriculum the selected blocks of knowledge must be translated into a profound educational experience, having a lasting effect on the competence and attitudes of the student.

This brings the writer face-to-face with the risk of paradox. Among the goals we are seeking in the work sciences are improvements in job satisfaction; job enrichment; greater participation and involvement. But teachers and students many need these also, within the university. Clearly, we should not try to prescribe at arm's length, and in rigid and excessive detail, the work which teachers and students have to do in the work sciences. We need to see the development of an effective curriculum as a process, itself a kind of learning experience.

With this caution in mind let us raise a few questions. How much (described either in words of syllabus or in hours of study) should be called for in any particular stage of engineering education?

Teaching takes the time of teachers and learning takes the time of students. And in any period of change – here we are thinking of changes in industrial processes and attitudes, changes in legislation, changes in colleges – teachers also have to spend time learning. Every administrator and curriculum planner in engineering education is conscious of a shortage of time. In dealing with the subject of this paper, therefore, we are involved in competition maybe even in conflict. We have to be ready to compromise, because every curriculum involves this.

One area of compromise concerns the question of stages. Some matters may appear essential at undergraduate level; others can be left, perhaps should be left, to graduate and specialist courses. The point here is that some things should not be missed because they are fundamental, and others will not fully be learnt until the student has some professional experience.

How can we arouse the motivation of students? Eagerness to learn can of course be inherent – the result of natural curiosity and intellecutal excitement. There need be no shortage of either in dealing with the work sciences. But sometimes more may be needed. Most teachers agree that, in the broader education of engineers, relevance is important. And it seems that relevance to other academic subjects is less influential than relevance to the future professional role and the problems this will entail. This presents a challenge to our ability as educators because, as work scientists, we see little value in coercion and threats of examination failure.

The last problem to be mentioned here concerns the recruitment of teachers. This is important because teachers – their values and attitudes – are part of the educational experience, a part of the curriculum. Is it better to have an engineer who has been properly trained in the work sciences (and can perhaps better establish relevance in the eyes of students), or a specialist in the work sciences who can offer a greater depth of knowledge and is more likely to be aware of (or involved in) current research? There is no general answer to this question, but this does not mean that appointments should be made without considering their implications. Teachers involved in interdisciplinary education should recognize the disadvantages and limitations inherent in their various backgrounds and seek to compensate in whatever ways are appropriate.

CURRICULUM POLICY

Here are some principles which, it is suggested, should underlie the teaching of the work sciences in schools of engineering:

In the competition for time, within the total curriculum, priority should be given to knowledge and skill which are academic, in the sense of being fundamental and requiring instruction in an academic environment. Matters which are largely practical can be learnt through practical experience or by independent studies from journals and handbooks as the need arises. Such practical aspects are likely to change from year to year (with, for example, minor legislation and regulations) and should assume a lower priority during intensive and expensive formal education.

Saving time should not always mean simply cutting out this or that subject. The emphasis should be on economizing. This can be achieved by improving the speed of learning through motivation and effective teaching and also by the multiple use of time – learning from two or more subjects simultaneously.

Each matter should be studied to a depth which is appropriate to its professional importance, having regard to the engineering speciality being studied by the student. The following categories are sometimes used: (a) appreciation level – general awareness of a knowledge area and its importance, and the identification of specialists whose professional assistance may be required; (b) working level – the attainment of a competence which enables the graduate to use the knowledge and skills directly, in meeting his or her normal professional responsibilities; and (c) research level – a high level of expertise, sufficient for the extension of knowledge and the development of technique. In the undergraduate education of engineers we are concerned with the first two of these levels.

Nothing should be taught which is not subsequently exercised by students, preferably in the analysis and solving of relevant problems within the total curriculum.

CURRICULUM ELEMENTS

The work sciences sections in the first year can include lectures, laboratories, seminars and study visits, with the emphasis on the fundamentals.

In the second year, various applications can be integrated in the courses – for example criteria for comparisons between technical efficiency requirements, economic considerations and human factors. In the fourth year, many opportunities are provided for the students to integrate what they have learned about business and organization theory, industrial psychology and work supervision, with the emphasis on applications. These applications should be based on the manner in which individuals and groups function in industrial contexts.

Below are some examples and suggestions which are also summarized in Table 1.

Ergonomics (see Fig. 2). In its practical application ergonomics relates to two main areas: (a) the adjustment of man to work and the work environment with the aid of vocational counselling, education and training, suitable job placement, follow-up of work adjustment and different measures of habilitation and rehabilitation; and (b) technical and or-

TABLE 1. Examples of practical applications

Field of engineering	Applications
Mechanical and production	
Production process design	Systems theory of work sciences Machine design Design related to body posture, muscular strength and body movements
Materials and machinery	Ventilation criteria, thermal control
Light electrical	Use of ergonomic criteria
Design of electrical systems and equipment	
Electrical measurement	Measurement of physical and environmental factors
Electrical engineering	Radiation hazards, electroacoustics, control systems
Heavy Electrical	
High-voltage engineering	Safety in high-voltage installations
Industrial power-supply systems	Design and protection of industrial power-supply systems
Control engineering	Interplay between human and technical factors
Chemical	
Inorganic and organic chemistry	Toxicity, hazards and control of chemicals
Analytical	Permissible levels and measurement of hazardous substances
Chemical engineering	Permissible limits for both working and external environment Control measures, design and selection of process equipment

ganizational adjustment of work and the work environment to human needs capabilities and limitations.

Mechanical and production engineering. Mechanical engineers require a basic education (which may well be provided in common with other curricula) in biology, occupational physiology and psychology during the first two years. Industrial ergonomy, on the other hand, should be dealt with in the fourth year, when the students have a better background. Industrial applied psychology and work supervision, as well as industrial and environmental hygiene, can also be treated in the fourth year. The rehabilitation of physically handicapped persons and the problems of young and old workers should be examined.

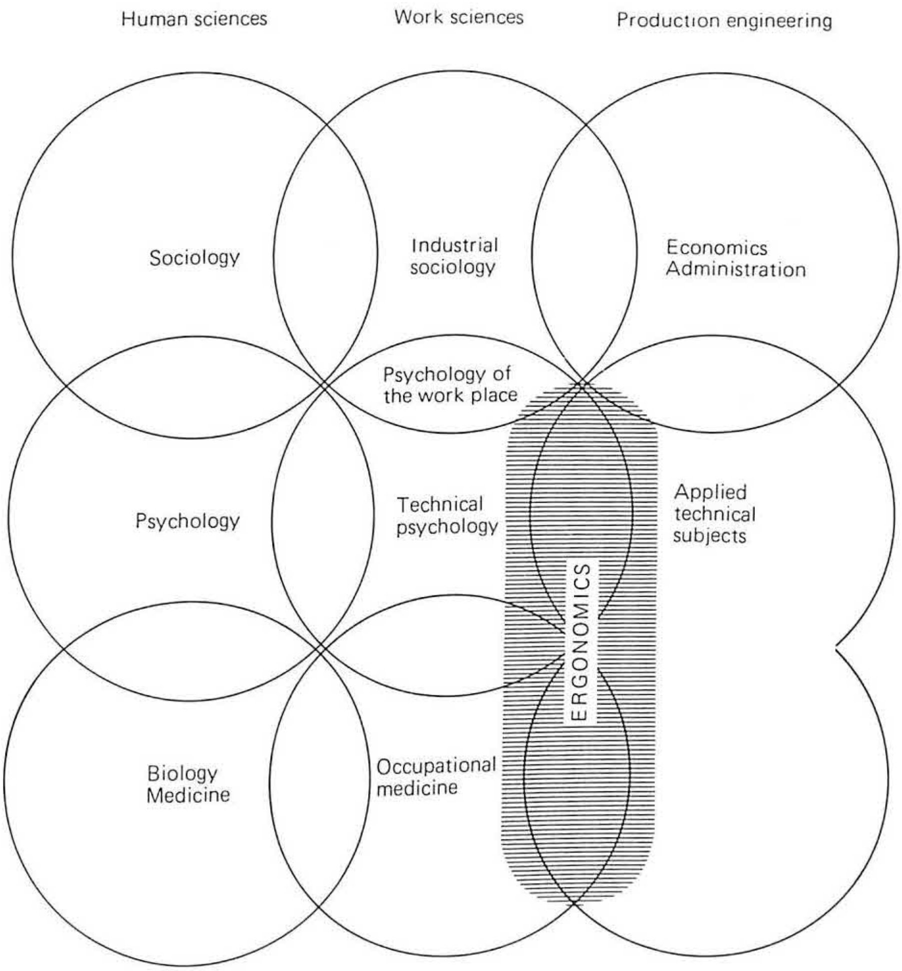

Fig. 2. Ergonomics deals with technical applications

The industrial and environmental hygiene section in the fourth year should deal with general principles for achieving and maintaining environmental and working conditions which are optimal for the individual, taking into account the various limitations of the individual. This should include comparative hazard analyses and a critical evaluation of threshold limit values. The industrial hygiene exposure diagnosis should include an analysis and evaluation of the environmental hazards of chemical agents, physical agents and ionizing and non-ionizing radiations. Further sections should deal with preventive and protective measures, industrial ventilation, dust collection and gas cleaning, the treatment and storage of waste, the use of personal protective equipment, etc. Special emphasis should be laid on emission and immission control.

Electronic and electrical engineering. The education of electrical engineers should include sections which deal with safety in the design of electrical systems and equipment. The psychological aspects of, for example, computerization and mechanization should be treated. Applications of particular importance for electrical engineers are ergonomic demands on lighting and illumination, acoustics (particularly noise), electrical safety, information transfer and information processing, as well as particular applications within medical technology. The electrical engineer's job includes equipment and system design. Occupational medicine sections or related applied subjects should primarily be dealt with by the regular instructor, but further treatment should, where necessary, be provided by special lectures.

Electrical measurement. This can include measurement of physical and environmental factors, earthing, shielding of measuring systems, safety standards, etc. Electrical engineering should cover the effects of electromagnetic radiation on human beings, the planning of electrical systems, safety regulations, working environment problems within energy production, radiation protection, electro-acoustics, hearing damage, etc. High-voltage engineering should deal with safety demands on high-voltage installations, the design and protection of industrial power-supply systems, etc. Instrumentation engineering should include the measurement of working environment factors, etc. In control engineering, the emphasis is on the system and the interplay between technical and human factors.

Chemical engineering. Learning in inorganic chemistry should include regulations for chemical laboratories, the toxicity and hazards of inorganic chemicals, threshold limit values, the handling, marking and storage of inorganic chemicals, measures to be taken in the event of an accident, etc. Analytical chemistry can include a survey of measurement methods for determining levels of hazardous substances in the working and external environment, with a special emphasis on instrumental methods. Sampling methods can be illustrated in practical laboratory sessions. Organic chemistry should include safety regulations governing work with organic chemicals, thereshold limit values, the medical effects of organic chemicals, special environmental aspects with respect to organic chemicals such as chlorinated hydrocarbons, methods to detect the presence of hazardous organic chemicals in the working and biological environments, ecology and pollution-control technology.

Applied chemical engineering. This should cover control measures aimed at eliminating gaseous and particulate air pollution, and also equipment design aimed at preventing the discharge of harmful substances. Students should be taught and encouraged to use work-sciences criteria in the design and selection of process equipment with the aim of reducing or eliminating medical hazards. Process chemistry should include the selection of processes, alternative solutions, cost-benefit analysis, etc., from the viewpoint of work sciences. In chemical technology, the design sections especially should integrate the labour science and ecology sections. In surface-coatings chemistry, the occupational and environmental hygiene aspects of the handling of paints and varnishes should be covered. In polymer technology, the production and handling of monomers and polymers in plastics and rubber processing should be considered from the viewpoint of occupational medicine and industrial hygiene.

Construction (architecture, civil engineering and building). The first year should include some treatment of working-environment questions in connection with the psychology of perception, in relation to design and planning methods.

Second-year instruction can include extensive treatment of working-environment questions, particularly in connection with design projects, such as for small industrial plants. Various environmental applications involving ergonomic, medical and organizational matters can be integrated with technical and design subjects.

In the third year, various environmental questions should be integrated in building-function analysis. Working-environment problems within special types of buildings, e.g. automotive service shops, newspaper printing works, woodworking shops, hospitals, etc., can be described.

In the fourth year, the emphasis should be placed on design projects involving the planning of large-scale or complex facilities. Here, the working-environment sections are co-ordinated and integrated in the context of design methods in town planning, the study of forms, mechanical equipment, building construction, etc. Various pedagogical approaches can be utilized simultaneously: lectures, seminars, study visits, drawing and critical analysis. Besides the planning of buildings, facilities and areas, ways of taking into consideration the interests and wishes of employees in connection with the planning of industrial plants must also be discussed.

DEPTH OF STUDY

It has already been noted that the various curriculum elements referred to in this chapter require a depth of investigation which varies from one engineering specialism to another. In some contexts the student needs only a general appreciation of what may be involved and what further expertise can be drawn on if necessary. In other contexts the student needs more than this. He or she must be able to apply skills directly as part of the professional function.

In Table 2 this distinction has been applied using the terms 'appreciation level' and 'working level'. Hours of student time have been suggested only to give an order of magnitude. It is recognized that local conditions – types of industry, health and safety, regulations and traditional working practice – may mean that more or less attention is required.

A CASE-STUDY

It seems appropriate to end this chapter with an example of how a case-study can be used in education concerning the work environment.

Table 2. A framework of curriculum for undergraduate programmes in engineering elements[1]

Subject areas	Mechanical production engineering		Light electrical and electronic engineering		Heavy electrical engineering		Chemical engineering		Civil engineering and building	
	AL[2]	WL[2]	AL	WL	AL	WL	AL	WL	AL	WL
Accidents and safety	5–10	5–10	5–10	5–10	5–10	10–15	5–10	10–20	5–10	10–20
Occupational Medicine and industrial hygiene	5–10	10–15	5–10	5–10	5–10	10–15	5–10	10–20	5–10	10–20
Work physiology	5–10	10–15	5–10	5–10	5–10	10–20	5–10	10–15	5–10	5–10
Technical psychology	5–10	5–10	5–10	10–20	5–10	10–15	10–15	5–10	5–10	5–10
Psychology and the work-place	5–10	10–15	5–10	10–15	10–15	5–10	5–10	10–15	10–15	10–15
Industrial sociology	5–10	5–10	5–10	5–10	10–15	5–10	10–15	5–10	10–15	10–15

1. The figures indicate the minimum–maximum hours of study expected of students in each subject area and each type of programme. The figures cover both hours of contact with teachers and time spent in laboratories, visits, library and projects.
2. AL denotes appreciation level; WL denotes working level.

The example chosen is only one of many cases which are already being used, successfully and otherwise, in a wide variety of courses on the work environment. It is not suggested that the case approaches perfection or that the way in which it is used leaves no room for improvement. The reason for using a single example from only one of the many subjects in the field is that only by considering in depth the procedure which can be followed, and the learning which can be achieved by students, will readers be able to appreciate the special contribution which case-studies can make. They may also be inspired to reconsider the ways in which they already use cases of one kind and another, and to write case-studies of their own. For detailed guidance on this and for up-to-date information on engineering cases (many of which involve certain aspects of the work environment) an approach should be made to the Engineering Case Library of the American Society for Engineering Education. The papers by Kardos, Smith et al. can be obtained from the same source (Kardos and Smith, 1979).

Why should case studies be used and what are their special merits?

1. They build up and revive motivation and help students to see meaning and purpose in studies which may otherwise appear mainly theoretical.
2. They help to integrate and assimilate information before it is forgotten, and prepare it for use in the real world.
3. They help to foster investigatory skills and the development of insight, both of which may otherwise be acquired only in the types of situations which case-studies depict.
4. By placing students in the position of people confronted with live problems, uncertainty and sometimes risk, they show how it is possible to learn from a situation more than can be learned from a lecture.

The last point poses a further question. Why not rely on direct experience itself? To answer this we need to appreciate the general point that all education is about saving. It saves time by accelerating learning. It saves resources by concentrating the efforts of those who are qualified to teach. And it saves people from the consequences of ignorance and trial-and-error. In our field of studies, for example, the aim is to save people from injuries, ill-health, and alienation in industry. We cannot wait for learning-by-chance, and we cannot affort it anyway.

The second reason for not relying on so-called 'practical experience' lies in the state of the art. To benefit from experience the learner often must rely on the insights and interpretation of someone who knows more than he or she does. The work environment is a relatively new field, even if it does draw on established academic subjects, and it is only where people with the latest knowledge and technique have been brought together for education and research, that the learner can expect the interpretation on which learning-from-experience largely depends.

A case-study is not simply a piece of micro-history, to be transferred from the memory of the author to the notebook of the student. All too often one hears of students being sent off to 'read' a case-study or, worse still, of a teacher 'delivering' a case as a lecture. Cases are not to be read or delivered or lectured or even merely discussed. Cases should be experienced – as puzzles, angry arguments, frantic searches, long silences, stumbled tentative suggestions, perhaps even a gasp of surprise. Their success is proportional to the silence of the teacher, once the problem has first been posed.

It follows then that the value of case-studies depends more on the skill of the teacher in devising and presenting the case, than it does on the choice of the subject. In the example which follows the intention is to show how a case may be staged; how it may be used to reveal to students the twists and turns, the unexpectedness, of situations confronting those responsible for improving the work environment; and how a rich educational experience may be generated by a single episode.

THE ARM-REST CASE

The case was devised and written, and is regularly used, by Dr Dennis Else, Senior Lecturer in the Department of Safety and Hygiene at the University of Aston in Birmingham (United Kingdom). The Department Head is Professor Richard Booth.

It is used in a six-month graduate diploma course for government inspectors and industrial health and safety advisers; in the undergraduate programme in safety and health; and in the complementary studies course taken by engineering undergraduates. Although the differences in level and prior experience of these groups of students may be reflected in the presentation of the case, and also in the penetration which students achieve, the basic structure and approach appears generally valid.

The case usually occupies about four hours and appears, in the diploma course, towards the end of a module on environmental control. This covers noise control, control of airborne contaminants, lighting, and the thermal environment. The objectives and content of the airborne-contaminants part of the module are described in the Appendix, page 46.

While the case seems initially to pose a problem in the design of extract ventilation, it turns out to have wider implications and tests the imagination and creativity of students in ways which they generally do not expect. This feature is referred to again, below.

It is important to know that students in both the undergraduate and diploma courses have early instruction and practice in the skills of small-group discussion and in the oral presentation of ideas and conclusions to large groups (video recordings are made and commented on as part of this training). There is of course no need to justify this investment of time and effort, which is reflected in the performance of students in the case-study and, no doubt, in their subsequent careers.

Statement of the problem

The company is a supplier of components to the motor industry. It manufactures a large range of polyurethane-filled vinyl components for the interiors of cars. The particular problem with which it approached the investigator concerned the manufacture of polyurethane-filled arm-rests for a saloon car (i. e. the soft cushion arm-rest fixed to driver and passenger doors). The processs can best be described by reference to the plan view of the work-place in Figure 3. Six people work along the bench beside the conveyor track. Another person operates the polyurethane foam-injecting machine at the end of the bench. The hygiene problem relates only to the operators at the bench beside the track, and therefore the jobs of other people in the work-place are not described.

The operators are engaged in removing the completed arm-rests from moulding blocks and replacing them with the arm-rest covers ready to be filled with polyurethane foam. They therefore have to pull a mould from the track on to the work-bench in front of them, release the locks on the moulding block and take out the completed arm-rest. They then have to spray the moulding block with a mould-release agent, and similarly spray an arm-rest cover before placing it in the moulding block, which is then locked an pushed back on to the conveyor track. The mould then travels down the conveyor to the position where the polyurethane-foam injector operator fills it with polyurethane foam. The mould then travels on through the curing tunnel, which is merely a heated and ventilated canopy over the conveyor.

The filled arm-rests are placed on shelves standing behind the operators and subsequently removed by other employees. The same shelves hold the supply of covers, ready for spraying and insertion in the moulds.

For several months, before the investigator was contacted, it was noticed that the operators beside the bench became rather drowsy by the end of their working shifts. It was thought that this drowsiness was probably brought on by the effects of exposure to the materials in the aerosol cans which were being used for spraying mould-release agent on to the covers and into the mould blocks, before the covers were placed inside the moulds.

How the case-study is organized

The briefings and report-back sessions take place in a lecture theatre and students are provided with small rooms in which to work in groups of

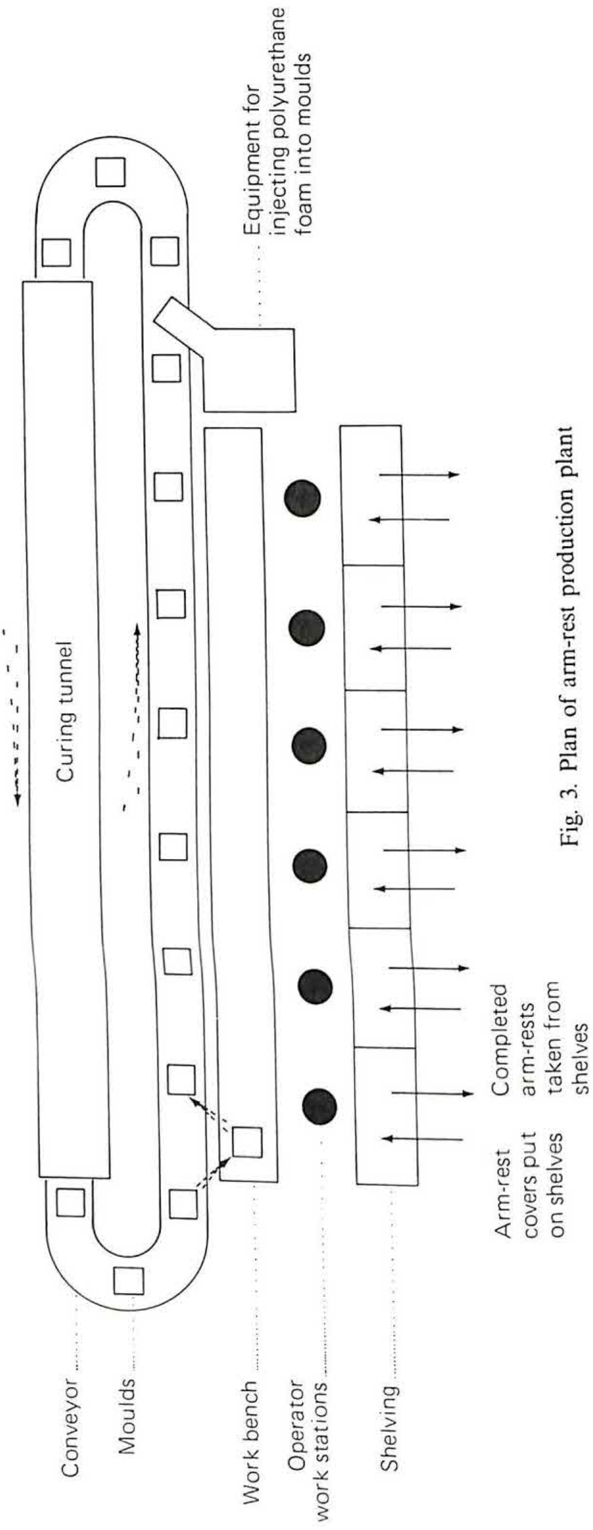
Equipment for injecting polyurethane foam into moulds
Curing tunnel
Conveyor
Moulds
Work bench
Operator work stations
Shelving
Arm-rest covers put on shelves
Completed arm-rests taken from shelves

Fig. 3. Plan of arm-rest production plant

between four and six students. The case-study is handled in the following stages.

1. The first fifteen minutes spent in the lecture theatre are used to outline the problem, as described above, and extensive use is made of slides taken in the factory. Arm-rest covers, polyurethane-foam-filled arm-rests and the aerosol spray cans are available for the students to study.
2. The students are then sent away in their syndicate groups to 'brainstorm', using knowledge from earlier parts of the course, to suggest techniques for assessing the risks associated with the exposure to the aerosols. They are given fifteen minutes for this part of the case-study.
3. The whole class then meets again in the lecture room and one syndicate group, selected at random, is asked to present its initial suggestions. The other syndicate groups are asked whether they have any additional information to contribute. This session, which takes another fifteen minutes, ends with the presenter of the case-study outlining the techiques that were actually employed by the investigator in his assessment of the problem.
4. Since the measurements indicated that a problem probably existed, the students are then asked to work in their syndicate groups again and to tackle the problem of controlling the exposure to the contaminants. At any time during the case-study they can ask the teacher for additional information or return to the lecture theatre to see again the slides showing the factory and its work environment. Each syndicate group is given a flip-chart on which to summarize its conclusions.
5. All syndicate groups then come together for the report-back session. Two of the groups are asked to present their findings (with the aid of their flip-chart summaries). The other syndicate groups then display their summaries and if necessary criticize the attempts of the first two syndicate groups. The case-study presenter finally adds any practical shortcomings or constraints not adequately covered by the syndicate groups in their reporting back. This session usually takes approximately thirty minutes. It may happen that a group proposes a solution which merits a long discussion; more time will then be required.
6. The presenter then describes a ventilation system design which was prepared by outside ventilation contractors. In essence this design proposed a duct running along under the bench surface with a grid at each work station, above which the mould or arm-rest cover would be held during spraying with the release agent. At the end of the bench the duct would rise vertically to a fan housing and vent at roof level. (The fundamental fault in this design is that the air velocity at the height of the job above the grid would be insufficient to capture

the surplus spray. It could not be made sufficient without discomfort and other problems. Another fault is that one or other of the operators occasionally moves her work near to a neighbouring work station, so that she can converse with her neighbour. Observant students can pick this up from the slides.)

These faults are not, of course, mentioned. The syndicate groups are given copies of the design and are asked to present on the flip-charts their appraisals of the proposed system. They have about twenty minutes for this.

7. During the next session one syndicate group presents its reasoning, with comments from the other syndicate groups. The teacher discusses in detail the inadequacies of the ventilation contractor's design, by drawing on calculations that were made and the results of an experiment in which a 'mock-up' of the contractor's design was temporarily installed as a demonstration.
8. Finally, the teacher describes the solution arrived at in practice, and relates this to the various suggestions made by the syndicate groups and to the general framework for controlling airborne contaminants offered in earlier lectures.

The outcome in the case

During the final stages of the case-study the teacher is able to show how the solution exemplifies a previously discussed approach to control of airborne contaminants–the hierarchy for control of airborne contaminants:

1. Substitution
    1.1. material
    1.2. process
2. Segregation
3. Ventilation
    3.1. receptor systems
    3.2. captor systems
    3.3. low-volume high-velocity systems
    3.4. dilution ventilation systems
4. Pesonal protection equipment

This model is discussed earlier in the course and one effect of the case-study is to demonstrate to students how useful it is. It is part of the teaching strategy that the class is not reminded of it at the beginning of the case-study. The temptation is for students to jump too quickly to the idea that the problem was simply one of designing a captor or receptor ventilation system. And yet, as the real-life solution shows, both substitution and segregation had a part to play.

It is interesting to note that the idea which led to the eventual solution came from a trade-union representative who had personal knowledge of the process and was aware of facilities available within the plant. This in itself raises a question of direct experience versus expertise.

The company had tried a number of approaches to control the problem. They were not in a position to invest heavily in automation. They had tried painting the mould-release agent rather than spraying it. They had tried using different types of mould-release agents. But they seemed to be thwarted in all their attempts by the problem of achieving adequate mould-release-agent coverage in the two deep recesses on the arm-rest cover. (They could not use a dipping system because this resulted in separation of polyurethane foam from the arm-rest cover.)

It was the trade-union representative who realized that there was no need for the arm-rest to be sprayed beside the track. She also realized that the company had a spray booth that was not being used at another part of the plant. It was therefore possible to change the way in which the work was organized as follows:

1. The arm-rest covers were sprayed with mould-release agent in a spray booth, in a separate operation. This enabled the agent to be applied from a spray gun which provided a cost-saving as compared with the use of aerosol cans. Each operator in turn took a batch of 'her' arm-rest covers to the booth, to spray them. (Segregation.)
2. The coating of the moulding block itself with mould-release agent was done by paint-brush. (Substitution of process.)
3. The mould-release agent applied to the moulding block did not have to be very powerful and therefore the chlorinated-hydrocarbon-based aerosol mould-release was replaced with a less harmful water-based mould-release agent 'soap'. (Substitution of material.)

LATERAL LEARNING

As already observed, a case-study encourages the student to utilize knowledge from earlier classes and courses and from prior experience. But knowledge can move laterally outwards as well as inwards; from the particular to the general. Conclusions, implications and repercussions can emerge from a case-study to widen the understanding and sensitivity of students and their ability to approach situations of many types. A few examples taken from the arm-rest case will help to illustrate this point.

The manufacturers of car components, at least in the United Kingdom, are often small companies. They operate in a competitive market and changes in car design or even changes in car models can put them out of business almost overnight. In fact, the production line in the case-study was closed down soon after the reported episode.

There are several reasons here why such a company should be hesitant about capital investment, in health and safety measures, or in other matters. A low-cost solution will always be preferred, and a solution which can be tried out cheaply, before a large sum is spent, will always appeal to common sense. Regardless of final merit the minor reorganization and substitution which was adopted, was pragmatically preferable to the construction of an extract system which might not work. This financial caution is not, incidentally, an example of conflict between workers and employers. The trade union did not wish to see its members become unemployed due to the company being overloaded with additional capital costs. The solution came, it should be noted, from a suggestion by a trade-union official.

Then there is a point about satisfaction. The union wants to satisfy its members. The employer wants to satisfy the union. There is a stage in the case-study at which students might recognize that the proposed extraction system would not work and yet be unable to devise a system which would work. They might put themselves in the position of the employers (and maybe of the union officials) and say (in effect):

> All right then. There is no objective solution to this problem. The choice is between sleepiness due to some unknown and perhaps unimportant toxication, and unemployment. If the ducting is installed and makes plenty of sucking noise, the workers will be much happier. Both the employers and the union will be seen to have done *something.*

This line of argument, thrown back to the class by the teacher as soon as it is offered, can lead to a heated discussion of immense value. The so-called Hawthorne effect can be referred to if necessary.

As a final illustration of lateral learning there is the point about the hierarchy model. The students often assume (for various reasons) that the problem is one of extraction-system design, but it is not. Only by taking one step back from the situation and applying a more general approach to the essential problem, can the safety-and-health adviser find the truly creative solution. The wise teacher will not say this himself at any stage, except perhaps when the case-study is completed. If it comes from the students, as their own discovery, it will be fully assimilated.

APPENDIX TO CASE-STUDY

University of Aston in Birmingham, Department of Safety and Hygiene

Objectives for the control of airborne contaminants part of the environmental control module

At the completion of the course the student should be able to:

1. In the case of a previously uncontrolled process: (a) select an appropriate ventilation system; (b) outline key factors that should be incorporated in the design of the system; (c) advise on commissioning, maintenance, training and record-keeping; and (d) advise on requirements for initial performance tests and routine ventilation checks.
2. In the case of existing ventilation systems: (a) decide whether the ventilation system is suitable for control of a particular danger and is functioning

adequately; (b) suggest improvements to the ventilation system or an alternative if the system is inappropriate; (c) decide the adequacy of routine ventilation testing and maintenance and whether the organization relating to the use of the system is satisfactory; and (d) suggest improvements for organization, maintenance, routine testing and training.

Topics

Control of airborne contaminants. Hierarchy of control techniques, substitution, segregation, total enclosure, partial enclosure.

Receptors, captors and low-volume high-velocity. Theory of point sinks, contrast between blowing and exhausting, capture velocity and factors governing capture velocity for different substances and different extract situations, advantages and disadvantages of receptor hoods, captor hoods, and low-volume high-velocity.

Dilution ventilation. Design principles, dilution factor, advantages and disadvantages.

System design. Energy losses and conversions in ventilation systems, static pressure, velocity pressure, total pressure, hood entry losses, key factors governing resistance of ventilation duct systems, system resistance, selection of transport velocity, selection of appropriate filtration method, selection of fan type size and speed on basis of characteristics and system resistance, consequences of incorrect fan selection, designing balanced multi-branch systems, consequences of installing incorrectly designed systems or breaking into correctly designed systems.

Ventilation monitoring instrumentation. Qualitative and quantitative methods, swing-vane velocimeters, thermistor anemometer, pitot tube, inclined manometer, smoke tubes and dust lamp.

Legal requirements for ventilation. Comparison of requirements set in specific technical terms and requirements based on objectives, historical development of legal requirements, record-keeping, maintenance and training.

Ventilation practicals. Practical tuition in the use of instruments. Assessment of the adequacy of the following: fume cupboard, portable welding fume control unit, dilution ventilation system.

Commissioning, monitoring and testing of extract ventilation systems. The role of environmental sampling, use of codes of practice and other standards, hood static pressure, information that should be sought at commission, frequency of visual and performance checks. Process and environment changes.

Reference

KARDOS, G.; SMITH, C. O. 1979. On Writing Engineering Cases. *Proceedings of Engineering Case Studies Conference*, Washington D.C. American Society for Engineering Education.

Appropriate technology in engineering education

A report based on a seminar convened by the Intermediate Technology Development Group, London

David Brancher

Introduction

This chapter, on teaching and learning in appropriate technology could have been commissioned from a single author or maybe a pair of authors. This seemed inappropriate, however, for at least two reasons. The debate about appropriate technology is one which now spans the world, engaging both developing and developed countries and concerning engineering education in many specialisms and at several levels. Its proponents would be the first to say that there are no all-embracing 'experts' in the educational aspects of appropriate technology. The scope is too wide and the implications are too profound.

The second reason for preferring a collaborative approach is that appropriate technology is essentially the movement of attitudes and the re-examination of values, in engineering and in engineering education. When it takes full effect it will do so as a new consensus. What is important at this stage is not the tabulation of scientific or para-scientific principles (if, indeed, such exist) but the shape and quality of the consensus.

For this reason it was decided to approach the subject through a series of discussions involving a group of engineering educators and practitioners. For reasons of economy the participants were invited from within one country, the United Kingdom. The meetings were convened by Intermediate Technology Development Group Ltd (ITDG), a non-profit organization formed in 1965 by a group of engineers, economists, scientists and others from the professions to provide practical and self-help techniques for developing countries. Through its subsidiary AT for UK, ITDG is now concerned also with the investigation of appropriate technologies for countries like the United Kingdom.

No claim is made that the experience and insight brought to bear by the participants is comprehensive and conclusive. It is, however, worth mentioning that the members of the group have, between them, practised engineering in thirty-seven countries and taught it in twenty-four.

All but seven of these countries are at an early or intermediate stage of development. The names of the participants are listed below. The inclusion of any name does not necessarily signify that the individual agrees with every contention in the report. Final responsibility rests with the editor.

Appended to the report are brief descriptions of some current curricular developments in appropriate technology in undergraduate engineering courses and programmes, a bibliography, and a list of relevant centres and journals.

Appropriate technology is not a concept which can easily be approached in a linear fashion and the wide-ranging nature of the discussions created problems when the report was first drafted. Eventually it was decided that a question-and-answer format, dealing with some of the uncertainties frequently expressed by teachers and academic administrators, would be the most reasonable–and appropriate.

Discussion: questions and answers about appropriate technology

What is appropriate technology? Does its definition tend to distinguish it from 'engineering'?

First, we should make it clear that there are no technologies which we can assume to be universally appropriate (although there are some which may be universally inappropriate). Judging appropriateness is a matter of applying certain criteria. Definitions of appropriate technology can be of two types. The first type attempts to be objective and factual. For example:

> Technology which is appropriate to the context of its application; which tends to respect its environment (in the comprehensive or systems sense) and not to change it except as specifically required; which is selected without regard to external prestige or scientific status.

The second type of definition is subjective and tendentious, and difficult to encapsulate because a debate about the meaning of technology is part of the concept. It sees appropriate technology as a social movement, international and essentially humanitarian, towards technologies which can meet fundamental needs and aspirations at low social and ecological cost and through an indefinite future. The criteria in Table 1, adapted from Nelson and Yudelson, seem to represent the general consensus.

Perhaps the way to resolve the problem of reconciling a definition of appropriate technology with the concept of technology in general, is to seize on the word 'engineering'. Of course, technologies can be appropriate or inappropriate in a particular context. But engineering as a profession, as an activity described by one of its oldest professional bodies as being 'for the use and convenience of Man', can only be concerned

TABLE I

Appropriate	Inappropriate
Ecological factors	
Does not release pollutants/poisons to environment	Pollutes/poisons environment
Protects existing natural habitat	Destroys natural habitat
Restores viability of ecosystems	Destroys viability of ecosystems
Recycles organic nutrients/creates topsoil	Wastes nutrients and destroys topsoil
Produces food	Destroys food production (potential or actual)
Conserves renewable resources so that renewal can continue	Overuses renewable resources
Conserves nonrenewable resources	Uses and wastes nonrenewable resources
Promotes use of renewable energy sources	Uses nonrenewable energy sources
Promotes use of recycled materials	Does not use recycled materials
Reduces transportation dependence	Increases dependence on transportation
Economic factors	
Long life	Short life
Promotes small-scale production, local ownership and control	Promotes large-scale centralized enterprises
Promotes meaningful work	Results in dehumanising/impoverishing work or lack of work
Labour/skill-intensive	Capital-intensive
Social/political/cultural factors	
Promotes social flexibility/adaptability	Reduces social flexibility
Promotes self-reliance and community co-operation	Promotes centralized control
Understandable/usable at community level	Understandable only to, and run by, specialists
Creates/maintains natural beauty	Destroys natural beauty

Adopted from L. Nelson and J. Yudelson, *Criteria for Appropriate Technology*, Sacramento, Office of State Governor, 1976.

with appropriate technology. If engineers use technologies which are inappropriate, they are negligent. If they do not know what is appropriate they are ignorant. And if they do not care what is appropriate they lose all claim to professional status. Appropriate technology, then, implies no more and no less than a return to the fundamentals of engineering and the better solution of engineering problems. It is essential in its own right and not only because of a particular crisis in the world.

Something must be added to this, however. In a world which is changing fast, where engineers are or should be concerned with future viability, the key skills lie in anticipation. Rich countries have in the past been able to make mistakes–in public policy, industrial development, and the exploitation of resources for example–and yet survive. Poor countries, however, have had to consider the consequences of failure. But now, and increasingly, all countries must anticipate the shortages and other crises of the future and devote their investments of material and manpower to goods and services which will remain viable in the long term. The engineer's role in this collective anticipation is crucial. An education in appropriate technology should prepare him for it.

But surely appropriate technology is only about extreme poverty and the need for development?

It is probably true that development problems, the ideas of people like E. F. Schumacher, and the concept of intermediate technology have been prime causes of the current interest. Schumacher developed the concept of 'intermediate technology' in the mid-1960s. He argued that poor people in poor countries needed technologies that are relatively small, simple and capital-saving; and that these would be appropriate to meet the needs and resources of poor communities. His approach focused attention upon the fact that technology is not a fixed or 'given' factor in development, but one that is variable and adaptable. The coining of the term 'appropriate technology' certainly derives from this recent background and the need to find a label which is more generally valid and not tied to a particular scale of hardware. But criticism of indiscriminate technology and the social and ecological damage it can cause is at least as old as the Industrial Revolution. It is voiced today in rich countries perhaps even more than it is in countries at an early stage of development.

Is appropriate technology confined to engineers at professional level?

Of course not. If appropriate technology means often choosing simplicity rather than complexity, or local resources rather than imported materials, it follows that all levels of skill are implicated. This leads to an important point: appropriate technology often depends on suitably trained people to maintain and operate it. All too often operation and maintenance cannot be carried out because the educational system is top heavy, and craftsmen and technicians are not being properly trained in sufficient numbers. No technology worth the name can be appropriate if the training system of the country is inappropriate to social and economic needs.

What are the educational aims of appropriate technology in engineering education?

It is clear from what has been said already that to attempt to list these would be to explore engineering education as a whole. But by treating appropriate technology as a new or revived emphasis within engineering education, it is possible to suggest some aims which should be clearly articulated:

1. The ability to distinguish and approach the relevant social purposes of engineering.
2. A curiosity concerning the context of a given problem and an ability to analyse and describe that context.
3. An ability to see a range of alternative solutions and outcomes.
4. A readiness to apply appropriate criteria in the choosing of a solution without undue regard to scientific or technological status; in other words to judge one's engineering against the needs of people who are not engineers.
5. The determination to ensure that decision-takers who are not engineers and the public are made fully aware of the potential harms and benefits of particular technologies, and act accordingly.

We all know that administrators, teachers and students in all countries, are influenced by matters of status. How does this affect the introduction of appropriate technology?

There is no doubt that a preoccupation with status is a major barrier to the rational use of technology for social and economic development. It is characteristic of technological man that sophistication becomes an end in itself; that scientifically difficult technology carries more prestige because it is difficult.

The symbolism of technological hardware also comes into this. A large factory is more 'visible' than a hundred small workshops; 20 kilometres of motorway more visible than 200 kilometres of rural roads; a nuclear power station more visible than several hundred thousand local solar or biomass units. If this symbolism is extended by the camera, and by the photos which adorn the walls of government offices and the pages of technical journals and newspapers, its influence becomes pervasive in ways which those involved may not be aware of.

The visibility of high technology also means visibility and a kind of status for those responsible. The international journals and conferences in technology play a part in this by supporting the personal ambitions of administrators and technologists. Ambition is not of course dishonourable. But if technology is to develop its full potential in creating true wealth and reducing real poverty, technological ambition must be better focused than it has in the past.

Administrators in higher education are not immune to the above influences and academic teachers feel them as much as anyone. But the question of status goes further still in the design of courses and qualifications. An appropriate-technology approach in engineering education sometimes appears to lack the distinct and definable body of theory associated with the 'hard' sciences. It cannot always predict the useful areas of the social sciences. The need-centred approach makes such pragmatism inevitable and yet many administrators and academics are disturbed by this conceptual untidiness, or fear it is a cover for sloppy thinking.

Suspicions as to the academic status of the appropriate-technology approach are reinforced when it comes to matters of experimentation. The scientific norm is to approach problem-solving via hypotheses which can be stated theoretically and then subjected to the elegant experiments needed to prove or disprove the postulated theory. In appropriate technology, experiments are likely to be more rough-hewn. The problem-solving is more likely to involve full-scale hardware set up in the field, and is used as much to generate ideas as to suggest or justify theory. Intuition often plays a part in this, and both intuition and imagination have become neglected in engineering education. Practising engineers can argue, quite rightly, that a return to a more even balance between intuition and theory, and to a result-centred pragmatism, would be a return to the traditional strength of engineering. But many academic engineering scientists do not see it this way.

Perhaps the best insight into the problem of status is given by the notions of 'hard', 'soft', and 'wicked' problems. Hard problems can be stated precisely and objectively. Answers to them are 'right' or 'wrong' using inflexible criteria. Soft problems are more difficult to define, definition depending often on the viewpoint of the individual. Criteria are more difficult to decide and apply and it is often difficult to know, at least in the short term, whether the problem has been solved or merely transformed. Wicked problems are extreme forms of soft problems in which the problem-solvers are part of the problem.

Hard problems are the substance of much that is taught in science at all levels of education. Because they are clear-cut and tidy, and because success is immediately visible, they provide the ladder for academic status and careers. Needless to say, they are easier than the soft and wicked problems which pervade not only appropriate technology but almost every professional challenge in the real world. There is therefore no need for advocates of appropriate technology to feel worried about the true status of their work. But they do have to understand the preconceptions of those they try to convince. In particular they need to recognize that standards of student attainment must be maintained and where possible raised. They must be ready to show, to their sceptical peers, that students educated in appropriate technology become better engineers than those who are not.

Are there any fundamental differences, in these problems of status, between developed and developing countries?

No.

Should appropriate technology be handled as a distinct course or course-unit?

Appropriate technology is no more and no less than a return to, or reaffirmation of, the fundamentals of engineering 'for the use and convenience of Man'. It can be argued therefore that it is not only wrong but ridiculous to treat it as something separate from the core of engineering studies. It should pervade the whole of the curriculum. Its aim should be the development of a new ethos in engineering education and eventually in engineering itself.

But this is counsel of perfection. It takes no account of the problems of reform–the need to convince colleagues and to build up educational materials, new contacts outside the university, new learning strategies, new modes of assessment. In the short term at least it is necessary to set aside blocks of time and to encourage staff, so that a need-centred and problem-based approach can be developed without risk of being sucked back in the old ways of abstraction and social detachment.

Whether these structural arrangements within the curriculum are called appropriate technology or, for example, 'engineering and development', or 'engineering and human needs', is beside the point. Advocates of appropriate technology claim no special authority to decide what is appropriate or inappropriate in a need-centred education. It is the intention which matters, not the title.

How can one know whether appropriate technology is 'covered' in the curriculum; whether it is being handled successfully?

There are two ways, which support each other. One is to use some sort of check-list, perhaps similar to that given near the beginning of this discussion, and see how the curriculum reflects the criteria of an appropriate technology. In most cases it is necessary to be selective using these criteria, having regard to whatever may be the specialization of the degree programme. But if students can say something sensible about most of the criteria and their application to the type of engineering they are studying, then some success has been achieved.

The second way is more critical because it requires doing and not merely saying. We come to the question of learning methods below, but already it is clear that active learning, through projects and the like, is essential. Quite simply, if students perform as sensible and imaginative problem-solvers in their projects; if they want to know, and show they can find out, most things of significance in the formulation of their problems; if they can identify, and care about, the human and ecological factors involved, then educators are succeeding in producing appropriate engineers.

It is this sort of suggestion, however, which worries university administrators. They are used to the precise measurement of success-indicators, even though the validity of many such indicators is uncertain. Perhaps this concern can be put in perspective by making an analogy. In an academy of music a musician is taking his final examination. The professors listen to him playing and give marks for such qualities as interpretation, expression and technique. They do not measure the speed of his playing in notes per minute. They do not award him a pass because he gets through the piece without making any mistakes. They grade him by his performance as a whole, having regard to what it means, in the world of music, to be called a musician. It is not mere rhetoric to ask why engineering teachers of quality should not be able, after some experience, to make a reasonably reliable judgement as to whether their students are learning the amalgam of skills we call engineering.

Which themes or problem-clusters are the most important in relation to present and future needs and the uses of technology?

Presumably this question is about choosing problems for teaching purposes; about structuring course units or modules around food, energy, shelter, urbanization and so on. There is no doubt that this approach can be very rewarding, but it is not the only way. The alternative approach is to direct the studies towards groups of people whose needs may be multiple–a neighbourhood or a village; a racial minority; a group of unemployed.

The two approaches are not of course mutually exclusive, but the second suggestion does emphasize the importance of identifying, with students, a set of clients. This certainly can have an effect on motivation. And if direct contact can be made, between students and clients, it means that the students have the benefit of feedback on the viability and acceptability of their proposals. It may even provide the chance of experience as change-agents–perhaps the most important role of all in development and environmental improvement.

Forgetting these social purposes for the moment, and remembering that engineering students must be competent in science, what kinds of problem have the most to offer in exercising the 'hard' skills of students?

It is a profound mistake to have preconceptions about this. There are probably few human needs which are unconnected with engineering, and certainly many where the 'hard' skills of engineering can unexpectedly be put to use. Just for example, some students at Imperial College, London, were asked to do a study of the 'meals-on-wheels' service in a London borough (the scheme whereby old people, living alone, are brought hot meals at midday). Their contributions, after detailed investigations, were to produce a computer program for scheduling the vehicles and to redesign the food-warming equipment.

Obviously some types of project hold more promise than others, but one should not be too certain in advance. Part of the excitement of appropriate technology, and part of the excitement it can bring into engineering education as a whole, is the discovery that engineering skills have enormous scope in their application.

It seems, then, that projects are the key to successful appropriate-technology education.

Without doubt this is so. But we have to remember that projects can take many forms. They can involve single students or small groups. They can be concerned with research, development, or implementation. They can be 'hard' and 'soft'. They can be closely formulated in advance or they can be 'open-started' as well as 'open-ended'. They can involve field-work, even though this must sometimes be ruled out. The scope is enormous and has been recognized only in recent years.

Bearing in mind that we all have limits to our knowledge and competence, and that students often have limited experience of the wider world, is it not difficult to know and convey the full environment of a problem?

Of course this can be difficult. The important thing is to make the most of opportunities. These include the real-world experience and interests of the teacher; the presence of students from the physical, social and cultural environment in question; links between the university and people outside. There is no point in attempting the impossible. The important thing is to recognize just how much is possible.

What about case-studies?

There is an important point here. Case-studies are often misused in education. There is little benefit in treating them as straightforward pieces of history, to be read to or by students as accepted and uncomplicated fact. The potential of case-studies lies in re-creating the uncertainties and confusion which faced the original problem-solvers; in forcing the students, at each stage in the history, to take decisions without knowing the next stages. This exposes the students to the realities of being an engineer. It forces them out of passivity into active involvement. It means that case-studies must be structured for this purpose, and we shall be coming back to this below.

And what about lectures?

It is increasingly fashionable to play down the importance of lectures. It is true that they are often misused, as a cheap means of conveying information which can be better handled in other ways. Someone once referred to them as a way of transferring facts from the notebook of the teacher to the notebook of the student without passing through the mind of either. And sometimes they merely feed the vanity of the teacher.

But this criticism can be overdone. The prime role of lectures is to build up motivation (and it takes a good teacher to do this). The lecture is at its most valuable when the lecturer is a first-hand witness, a real person from the real world, bringing in not only facts but also the attitudes and approaches of a real-world problem-solver. Teachers themselves do this, of course, and we have all observed the effect it can have on the motivation of students.

We have discussed the importance of knowing the context of a problem. Surely first-hand experience, by students, is important.

The vogue-word is 'experiential'. It can mean on-the-spot surveys and investigations; it can mean a visit of inspection; or it can mean living and working in the environment of the problem. There is no doubt that it is valuable, extremely valuable. But it is not essential and the financial and other difficulties in arranging it should certainly not be used as an excuse for dismissing whatever topic might be involved. Some academics are suspicious of such activity anyway. They think it is a waste of educational resources and it is true that it can be overdone. We must eye it critically, thinking always about educational purpose and effectiveness.

You are beginning to convince me. And yet I wonder about the resources, of all kinds, which are needed to develop appropriate technology education to its full capacity. Are we not short of them, particularly in developing countries?

Of course our colleagues in developing countries face great difficulties in engineering education. But some of these problems may be caused by an emphasis on the wrong kinds of engineering, on inappropriate technology.

In many cases the logistic problems of universities reflect the economic problems of the country. The problems of teaching a certain level of technology often reflect the problems of using that technology. Appropriate technology asks engineers to be clear-headed about aims and realistic about constraints. It also asks engineering educators to be no less clear-headed and realistic. When they are, about both their engineering and their education, some of their problems may be less, or different.

Let us be clear–all of us in developed and developing countries–the one thing you need in order to start teaching appropriate technology is a social problem capable of being solved by engineers. Once you have this, and the sense to recognize it, everything else is luxury.

You cannot get away with that answer. There must be some educational resources which are crucial. What about engineering teachers of the right type?

Every teacher can become 'the right type' if he or she is encouraged and helped by the administration. All too often the best careers come to those who concentrate on academic research or pseudo-research without regard to the needs of their country. Someone at the top, inside or outside the university, has to give a clear signal that appropriate technology teaching will be rewarded; that it is the most important thing going on in the school of engineering. Of course, people do not become competent overnight. It takes time to make a few mistakes and learn from them; to modify one's line of study and expertise; to get the feel of appropriate technology. But you cannot simply wait for new members of staff to join the school.

And other kinds of teachers can be involved.

Yes, you are right. All sorts of people, from other disciplines, can contribute in teaching appropriate technology. Economists are an obvious example (provided they can think beyond monetary terms). Sociologists, anthropologists, psychologists, ecologists, agronomists–all of these can be invaluable and we all have our orders of priority in looking at the list. Whether you can get help from them is another matter, because they too have senior colleagues watching their specialist research performance. It all depends on the way the institution is run and the quality of its leadership. If the engineering teachers cannot get help from such specialists they may have to do some wider reading for themselves. It is probably fair to say that engineers are often more adventurous in this respect than many others in universities.

What about help from outside the university?

There are two kinds of resources here. One is a group of people who are in need and are ready to help you help them to solve their problems (we have been over this already). The other kind are professional problem-solvers who are short of expertise or ideas, or simply short of time. Local government authorities and central government departments are among these. Depending on the general situation they can be very helpful, and very grateful for the help you can offer. Personal contact is the key to this – getting to know the officials concerned and keeping in touch with them.

Reference materials are in desperately short supply in the universities of developing countries, aren't they?

Yes they are. It is difficult to be specific about how crucial this is. It all depends on the sort of investigation involved, and the extent to which conventional reference materials would help anyway.

We have already discussed the use of case-studies. Are they scarce?

In way they are. You see, there are plenty of reports available (although sometimes difficult to get hold of) dealing with success stories. It is, of course, natural that someone who writes up his experiences should concentrate on the things which went right, leaving out all the false trails and wrong assumptions. But educationally this is a loss, because the purity and simplicity of the account means that some of the experience of problem-solving has been lost. It also means that it is difficult to handle the case-study in the stage-by-stage fashion described above.

And now the final question: What can national and international organizations do to encourage and assist the introduction of appropriate technology in engineering education?

There are all the usual activities to consider – conferences and workshops, scholarships, schemes for the secondment and exchange of teachers, and so on. Conferences which result merely in the exchange of platitudes achieve little. Workshops, on a smaller scale and regionally organized, can do much more, provided that the emphasis is on work. Every participant should take away something which he or she has helped to prepare, which can be put to immediate use in the classroom. All meetings, however, should recognize that ideas of innovation can quickly be lost when the participant returns to an institution which is educationally static. The Law of Inevitable Slipback is powerful and the most effective meetings are those where two conditions are fulfilled: (a) the head of department has agreed that the participant will be required to introduce the relevant content and ideas into the curriculum after attendance, and (b) some sort of follow-up meeting is programmed, to ensure that subsequent experiences are shared and discussed.

We noted earlier in this discussion that publication in refereed and international journals is an important activity for most academics. It is clear also that many specialist or sector journals of engineering science are unwilling to publish papers which lack, in the eyes of referees, the customary academic purity and scholarship. This leads to the conclusion that there is a place, as yet unfilled, for an international journal of cases in appropriate technology. Such a journal would have to be refereed, to ensure its status and value, but the criteria for the acceptance of papers would have to be carefully drawn up to ensure that the journal did not drift into the sterility and abstraction of many journals in so-called development studies. Above all, such a journal would have to give priority to education. It is only by fostering the spirit of appropriate technology among engineering students, at all levels across the world, that engineering education will help the people of the world to reach a viable future.

Seminar participants

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John Davis, Co-ordinator of AT for UK (ITDG Programme).
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Robert McCutcheon, Building Economics Research Unit, University College, London.
George McRobie, Chairman, Intermediate Technology Development Group.
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Terry Thomas, Department of Engineering Science, University of Warwick.
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Appropriate technology in the university curriculum

The following summaries describe the teaching of appropriate technology in various university programmes.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, LONDON – APPROPRIATE TECHNOLOGY IN THE DEPARTMENT OF CHEMICAL ENGINEERING AND CHEMICAL TECHNOLOGY

Undergraduate

Here, all the activities have been centred on final-year projects. Students work in pairs for a term on a research and/or design project. Over the last seven or eight years a number of these projects have been related to problems of development, e.g. studies on sugar processing (evaporator design).

The projects rarely produce definitive answers to immediate problems, nor is that their main objective. They play a very useful role in legitimizing and provoking an awareness of a range of problems otherwise neglected in undergraduate curricula.

Postgraduate

Teaching

For the last five years a 20-hour module on technology and development has been offered as part of the M.Sc. in advanced chemical engineering (a summary follows). The course is now also part of the obligatory 'core' of an interdepartmental M.Sc. in environmental technology and has proved extremely popular. It is taught jointly by a team of engineers (two from chemical engineering) and social scientists (two from the Department of Economic and Social Studies) and is evenly divided between lectures and discussions. The syllabus shows that the scope of the module is wide, and covers more than just intermediate technology. Rather, the course concentrates on a discussion of the assumption that science and technology are autonomous and value-free. Students read widely and write an essay and a technology-based case-study. In 1978, for example, case-studies included fertilizer production alternatives, cassava utilization, energy production for rural areas.

A second and related module on project choice and appraisal, with special emphasis on developing-country problems, was given for the first time in 1978.

These two courses form part of a complete one-year M.Sc. course (starting in 1978) on technology and development. Brief details of this are also given below. The syllabus and structures will integrate a number of themes currently being developed in the department.

Research Projects

A large number of projects relating to developing countries at M.Sc. (one-year) and Ph.D. levels have been conducted in the department. There has been no fixed pattern, and projects have included experimental studies, theoretical/analytical studies, collaboration studies (involving overseas field work).

Some recent project topics have included: extraction of protein from coconut-oil emulsions; kinetics of anaerobic fermentation (i.e. to methane); studies of high solids loading fermentation; pyrolysis of cellulosic matter; feasibility/system studies of alcohol production from sugar and cassava; study of alternative fertilizer technology with special reference to Africa; studies on optimum chemical process designs in developing countries.

Projects of this type can serve at least three separate purposes: (a) the educational development of the individual student; (b) the solving of particular problems (this is best done in a collaborative framework), and

(c) helping change general attitudes towards appropriate technology in the universities.

Technology and development – summary of 20-hour module

1. Developed and developing: What is 'underdevelopment'? Theories of underdevelopment and strategies of development based upon them.
2. Problems of development: modernization and industrialization; generating a dynamic (multiplier) of economic development; availability and control of resources; population growth and distribution.
3. The role of technology in development: world distribution of scientific and technical resources; 'technology gap' and technology dependency. Technology policies in practice and their implication. Scientific institutions in developing countries, especially research institutions.
4. The international ownership, control and transfer of technology: trade and aid agreements involving technology; cost requirements and problems in the international transfer of technology; patents, brand names/trade marks and their role in developing countries. Technology contracts and their conditions. Role of consultancy/design institutions in developing countries.
5. International corporations: their characteristics and objectives; their ownership and control of technology; their policies towards, and involvement in, developing countries. Implications of multinational investment for the economic development of developing countries.
6. Case studies: (a) development and current operations of a multinational corporation; (b) example of a technology contract: its background and conditions.
7. Indigenous and appropriate technology: choice of technology–scale and constraints. Purchasing, generation and adaptation of technology in developing countries.
8. Case study: choice of technique and choice of product, e.g. sugar production/sweetening agent.
9. Technologies for rural development: agricultural engineering; the green revolution; agro-chemicals, etc.
10. Autonomous development: a case study, e.g. China.
11. Student projects: essay; case-study.

M.Sc. in technology and development – summary of course

This one-year multi-disciplinary course started in October 1978. It provides students with an advanced training in engineering and an understanding and analysis of the nature of development and the role of technology in industrialization. The engineering component of the course comprises selected modules from existing postgraduate courses. The initial basis for the course is a selection of modules available in the Department of Chemical Engineering and Chemical Technology, but it is hoped to extend this arrangement to encompass other departments as soon as possible.

This course has a modular structure. The socio-economic components are presented as follows: there is an extended introductory module on the economic and social context of development – this is followed by modules which discuss the problems, methods and institutions involved in the choice, development, and transfer of technology, and discuss modern techniques of technology (project) appraisal. This work is complemented by seminars based on case-studies which play a major role in integrating the course materials and in providing a focus for multidisciplinary study. Students also undertake a major case-study on a subject relevant to the course and drawing on their background and training in engineering. Thus a considerable effort is made to relate the different components of the course to each other, with special emphasis on integrating the socio-economic and engineering studies.

Course outlines

The context of development. A background to provide the student with an understanding of the social and economic context in which the development effort is taking place. Particular emphasis will be placed on the economics of development and on the role of technology.

Sources and choice of technology. Problems and possibilities of acquiring capability: the transfer and choice of technology – an examination of the range (or potential range) of technologies available to produce products of similar functions and the evaluation of alternative technologies.

Project appraisal. Cost estimation and project appraisal with special reference to industrializing countries; methods of cost-benefit analysis; the implications and limitations of the methods of social cost benefit for the design of techniques and processes.

Case-study seminar. Case-studies are used to provide a breadth of comparative material which is not possible to provide elsewhere; they highlight the multidisciplinary nature of the problems to which the course is directed. They are also used to provide a forum for specialist outside lectures.

Major case-study (project). This is a multidisciplinary study involving socio-economic and engineering analysis. The engineering content of the case-study centres on the discipline in which the student has been trained and, where possible, on an area covered by one or more of the advanced engineering courses attended. It focuses on a specific developing-country problem. Staff with expertise and involvement in these specialist areas are also involved in the project supervision.

Advanced Engineering. This is a choice of some of the existing modules in other post-graduate programmes at Imperial College. For example, a student with a background in chemical engineering could choose three out of: systems modelling and control; chemical reactor analysis and design; computer-aided design; diffusive mass transfer with chemical reaction; biochemical reaction; biochemical engineering.

UNIVERSITY OF EDINBURGH – APPROPRIATE TECHNOLOGY IN THE SCHOOL OF ENGINEERING SCIENCE

The standard undergraduate programme lasts four years and the school offers specialties in electrical, mechanical and chemical engineering. Appropriate technology entered the undergraduate curriculum first in electrical engineering, but is now represented in all three specialties. The modes of learning and the fields of interest vary with the staff members concerned, and the aim of those interested in appropriate technology is to let its influence pervade the approach to engineering, and professional responsibility, throughout the school.

Undergraduate

Year I (all specialties): course of lectures on appropriate technology – students complete two 2,500–3,000-word essays, one on energy policy and one on other social implications of engineering.

Year III (electrical engineering): all students complete two studies or design projects. These reflect the interests of both staff and students and are frequently concerned with appropriate technology.

Year IV (electrical engineering – power systems): all students complete a long project and dissertation. The dissertation topics normally have an appropriate-technology theme. Recent examples are: (a) the environmental impact of an aluminium smelter; (b) the supply of electrical power to remote islands; (c) the selection of generation systems; (d) the effect on development of a comprehensive hydro-electric/irrigation scheme.

Post-graduate

Some studies are supervised jointly with the Science Studies Unit of the University at M.Phil. and Ph.D. level. Recent projects include: (a) the application of pedal power to agricultural processing; (b) the study of political and technological aspects of a comprehensive river scheme; (c) the use of tropical agricultural wastes as industrial inputs; (d) energy flow in subsistence agriculture; (e) the choice of new technologies at village level; (f) the spread of introduced technology in villages; (g) the technology of water sharing; (h) water utilization strategy; (i) social impacts of large-scale electro-metallurgical industries.

Many such projects are the result of first-hand contact in the field or suggestions and requests from overseas. It is common for post-graduate students to spend from eight to twelve months undertaking relevant field-work and to prepare for this with language learning where necessary.

BU-ALI SINA UNIVERSITY HAMADAN, IRAN – APPROPRIATE TECHNOLOGY FOR RURAL DEVELOPMENT

The undergraduate course in rural engineering is a four-year programme leading to the B.Sc. It was started in the academic year of 1977 when the first sixty students were admitted. As with all undergraduate programmes being offered by the university, the first year is spent in studying French (the second teaching language of the university) and in common-core courses, which include the natural and pure sciences, economics, sociology and an introduction to theories and philosophies of development.

The main part of the programme covers: (a) the application of engineering techniques to solving the environmental problems of existing technologies (for example, pollution control); and (b) the design and implementation of environmentally sound and appropriate technologies.

The student is expected to specialize in one field of study in which he/she will be competent, but at the same time not to lose sight of the fact that this programme should prepare him/her for a wide range of practical capabilities which he/she will be called upon to use after graduating.

The general objectives of the specialized sections of the course are, briefly: (a) to improve the student's basic theoretical understanding of the special field he/she has chosen; (b) to provide the student with experience in a repertoire of techniques which he/she will be able to apply with confidence; (c) to enable the student to carry out independent work in his/her own speciality; (d) to enable the student to go beyond merely applying his/her skills *in vacuo*, to being able to create the necessary infrastructure for the maintenance and reproduction of the civil works undertaken.

The main areas of specialization are described below.

Construction

The student is expected to become familiar with general civil-engineering techniques but in particular those techniques and materials suitable for low-cost and labour-intensive construction of roads and buildings in rural and marginal urban areas. The course makes use of standard civil-engineering texts, pertinent developments in the field of appropriate technology and traditional knowledge relating to construction.

Standard civil-engineering courses include: principles of construction; surveying; interpretation of architectural drawings and site plans; site investigation and foundation design; design and detailing of buildings and their associated services, such as public baths (*hammams*); water supply and sewerage.

These courses are integrated with case-studies and practical work in the field and laboratory in order that at a general level the student should be acquainted with:

1. The environmental, social and economic context of building in Iran, including; the state of existing housing stock in different regions; the nature of current demand; the structure of the industry; ownership and rents; skills and employment patterns; planning regulations; government organizations relevant to the construction industry, and basic literature relevant to the field of rural construction.
2. The organizational aspects of rural construction programmes, including time scheduling, supply of labour, materials and costing; climatic factors.
3. Traditional methods of construction, including mud brick and mud plasters, and the use of vaults and domes. He/she should be aware of the advantages and disadvantages of such methods relative to 'modern' techniques and of possible modifications to traditional methods.

Particular competencies include:

1. Ability to plan and independently direct a three-week project of construction work.
2. Managerial aspects of rural building projects, including labour, costing, scheduling weather factors and materials supply.
3. Geological and petrographic factors which may affect foundations, drainage, materials supply, village topography and the thermal characteristics of a site.
4. The sources of supply for all materials, organization of work to make best use of local materials; establishment of local supply facilities.
5. Traditional methods and materials and the ways they might be modified or combined with modern techniques to provide efficient and economical solutions to structural and housing problems.
6. Principles of climatic design, the design of structures which use the natural energy flows in the most effective manner; the social factors determining house form and structure and the design of appropriate

dwellings and public buildings; the technical requirements for special structures such as kilns, silos, barns and biogas digesters; special building methods such as those involved in earthquake protection.

7. Construction of rural roads to different standards; the ability to plan an appropriate transport network for a given locality.
8. Design, setting out and construction of elementary hydraulic structures such as dams, reservoirs, conduits and weirs.

Water technology

In the water-technology option extensive courses are given to provide the student with a sound theoretical knowledge of hydraulics, hydrology and water treatment. Other courses deal with the existing national water policies and planning in Iran. These provide a fundamental understanding of water as a natural resource in urban, suburban and rural areas.

The courses combine with practical work (in the laboratory and the field) and case-studies so that the student will be competent to deal with the following:

1. Planning, carrying through and evaluation of an independent project relating to water supply or sanitation, including understanding of techniques for primary, secondary and tertiary water treatment.
2. Basic methods of water storage and catchment including the design, supervision and construction of small earth- and rock-fill dams for water storage or the generation of hydropower.
3. Principles of irrigation engineering, including methods for reducing erosion, evaporation, seepage and salt leaching.
4. Supervision of the construction or modification of the physical elements of local water supply, such as pumps, channels, walls, *qanats* (see below), pipes and taps, in such a way as to meet the needs of a local population efficiently and economically.

In particular the student studies local needs and the proper management of water supply in the project area near Hamadan. This involves assessing the role of the traditional methods of water supply, particularly the *qanat* (an ancient method of tapping the water table by means of a gently sloping underground canal together with a series of wells which are used to construct and service the canal). In recent years this system has fallen into disrepair. Research undertaken by students and staff will assess: the basic effectiveness of the *qanat*; the reasons for its decline; the possibilities for revitalizing the method; alternative methods of irrigation suitable for local conditions.

Rural energy supply

This includes the study of:

1. National energy policy and the appreciation of environmental and

social aspects of energy supply at the national and local levels, as well as a study of the basic literature and a knowledge of organizations in Iran and elsewhere relevant to energy supply.

2. Existing patterns of energy use and energy needs in a given location and the general trends in changing use-patterns.
3. The range of alternative energy sources: i.e. the collection and use of solar energy, and its inclusion in the design of climatically appropriate low-energy buildings, biological sources of energy and the anaerobic processes for the production of biogas from animal and plant wastes; and the harnessing of wind and water energy for the production of electricity and mechanical power.
4. Assessment of appropriateness of various alternatives on economic, social and environmental criteria.
5. Engineering principles relating to rural electrification, including generation, control, storage, transmission and distribution of electricity.

Rural industries

This course includes studies of:

1. The general economic climate of Iran and the medium- and long-term trends in policy, including an understanding of the importance of maintaining an awareness of changes of government policy and economic trends.
2. The law relating to rural areas, and government organizations relevant to the productive sector in rural areas.
3. The range of common rural enterprises and traditional crafts (pottery, rug making, dyeing, leatherwork, textile production, clothes-making, furniture and cabinet-making, and production of agricultural equipment) in different parts of Iran, the economic, social and technical factors which gave rise to them, and the changes now being brought about by wider changes in the Iranian economy as a whole.
4. The principles of managing rural enterprises, of market analysis and marketing, the raising of capital and basic accountancy.
5. Technical and managerial principles of harvesting, storing, processing and marketing locally produced foodstuffs, and the economic possibilities of other natural products such as medicinal plants, wood, dyes, natural pesticides and animal products.
6. The prevailing types of agricultural implements and the methods for making and repairing them.
7. The central role of the general workshop in self-reliant development projects and the establishment and stocking of a small all-purpose workshop for making and repairing agricultural implements, household goods, energy-related equipment and other items.
8. Local demand for construction and the nature of local construction

activities; the establishment of organizations for the provision of materials or technical assistance in construction projects.

LANCHESTER POLYTECHNIC COVENTRY, UNITED KINGDOM – APPROPRIATE TECHNOLOGY IN THE DEPARTMENT OF COMBINED ENGINEERING

Introduction

The department believes that engineering is a profession for those with a broad outlook. Industry seems to be increasingly conscious of responsibilities to its work-force and to society at large, and senior managers are being chosen from engineers who can respond to the world around them and have the imagination to anticipate future needs. The aim of the degree programme in combined engineering at Lanchester Polytechnic is to provide these future managers with the opportunity to engage with problems which have not only technical but also social and commercial dimensions. The implication is that technology must be appropriate to its total environment and not only for purposes of economic development.

Basic programme

The programme consists of modules at four levels, corresponding to a possible total of four years of study. First-level modules are taken by those students whose secondary-school final certificate, while otherwise satisfactory, does not include maths and science. Fully qualified students begin with the second-level modules which provide a grounding in the fundamentals of electrical, mechanical and manufacturing engineering, together with the principles of computation, experimentation and design. The third and fourth levels of module, from which the student selects the programme which best fits his or her requirements, deal with advanded studies in the engineering disciplines, manufacturing and commerce.

At the third level there are compulsory modules dealing with practical skills in experimentation, design and management. At the fourth level the practical modules, also compulsory, deal with design. Much of the practical work, at all levels, takes the form of projects. These may be tightly constrained, and therefore more straightforward, at the lower levels. At the higher levels the problems have greater breadth and complexity and the constraints may include restriction of cost, available materials, manufacturing processes, assembly methods, use of proprietary products, maintenance, safety, legal requirements and social acceptability in general. All of these factors contribute to the judgement of appropriateness, making students aware of the many criteria which should be considered in selecting a solution to a given problem.

Project work

Some of the project work is undertaken by groups of students. Recent examples include the design of a small car for city centres, severely limited in its dimensions, pollution-free, legally acceptable and socially attractive. Another example is the project of designing a greenhouse unit for intensive food production. The unit had to achieve optimal use of solar and other renewable energy, and minimal dependence on fossil fuels. Fulfilling the environmental needs of the food-plants, the design had to meet the constraints of manufacturing processes and costs.

A third example of a group project is one concerned with the problems of physically handicapped people in a nearby shopping precinct. Most attention was given to the need for mobility, affecting both the handicapped and the non-handicapped. Assessing appropriateness involved not only materials and components but also such matters as the availability of finance.

As well as taking part in a group design project, most students undertake an individual project during their final year. This takes up at least four hours a week for thirty weeks. It is felt to be important that the student should work on something which holds personal interest, and it sometimes happens that theoretical and experimental matters crowd out economic and social considerations. The staff of the department do not regard this as satisfactory, and students are therefore encouraged to select projects which relate the formulation of the problem and proposed solutions to the social and economic context.

It has been found that the weaker students are unable to cope with this complexity and choose to bury themselves in the detail of experimentation. The best students, having taken the message of their first design classes, react otherwise. They welcome the chance of undertaking a project which allows them to reflect on the background to their chosen problems and the socio-economic implications of their proposals.

The diversity of the topics may be judged from a few examples of recent individual projects. One, by an Iranian student intending to set up a small manufacturing business, involved a study of the economic structure of Iran. Another, by an immigrant to the United Kingdom, dealt with the reasons for high labour turnover in a local factory. A Gibraltarian student (who now has a senior position in Gibraltar's telephone service) carried out a study of the future of telecommunications in the Peninsula. The final example is an assessment of transportation planning in the Midlands region of the United Kingdom.

From this brief note it is clear that appropriate technology is not treated as an abstraction or as a separate topic in the department, but as an essential aspect of all design teaching.

UNIVERSITY OF WARWICK UNITED KINGDOM – ENGINEERING DESIGN AND APPROPRIATE TECHNOLOGY IN THE DEPARTMENT OF ENGINEERING

For nearly four years, members of the Engineering Department variously interested in alternative technology, intermediate technology, design and the public assessment of technology have been discussing how and whether these topics should be taught at undergraduate level. A school survey in 1975 revealed strong interest in a course which related engineering to broader social objectives. During the last three years there seems to have been a swing from 'liberal' courses towards 'vocational' ones in student preferences. However, interest in alternative technology continues to grow, intermediate technology is being fostered by a number of governments and agencies (e.g. India, World Bank) and at home the depressed state of the small-firm sector of the British economy has attracted much attention. The department has therefore devised a vocational course to serve students who wish to work in small firms, overseas rural development or self-sufficient communities, or who aspire to be project engineers in conventional (i.e. large-firm) industry. A correspondence with about fifty organizations during recent months confirms that there is considerable interest in graduates who are technically versatile, conversant with socio-economic constraints on design and production and ready at least to consider a role as entrepreneur rather than employee.

The degree programme set out below has about 70 per cent of lectures in common with the existing engineering science course. It is based on mechanical engineering and is somewhat less mathematical than the other engineering degrees at Warwick. There are no options in the first or second years, but in the final year students may specialize in production and design, in overseas development engineering or in technology assessment. Agricultural engineering is given some prominence in the course, because it is important in rural development, because it is a field in which small firms are especially active and because it offers a good medium for the study of design, production and distribution of equipment. The laboratory work during each of the first two years has been set at about 100 hours only, to allow a further 100–150 hours for design exercises. In this respect the course is closer in teaching style to architecture or industrial design than to engineering. It is hoped that in the second year the exercises will include the establishment and temporary operation of small companies, as has been successfully done in some schools.

Liaison already exists with a number of local organizations in the agricultural, intermediate technology and small-firm fields as well as with national organizations. The programme will start in October 1980, and the targets for the first three intakes will be fifteen, twenty and twenty-five students.

Course programme

TABLE 1. Year One

Course	Hours		
	Term 1	Term 2	Term 3
Classical thermodynamics	20		
Lumped systems	20		
Design process	10		
Materials technology			15
Engineering maths (part)	25	20	
Engineering mechanics	20	10	
Elasticity		10	
Three-dimensional studies			12
Application of thermodynamics		10	
Electricity			15
Man in the environment		15	
Monsoon Asia		15	15
Alternative technology in the United Kingdom	10		—[1]
Engineering laboratory		80	
3D exercises		30	
Design exercises		120	
Tutorials		30	
Seminars on monsoon Asia		18	
		278	
Fieldwork (regional study of technology)	1 week in summer vacation		

[1] Alternative technology in United Kingdom (first-year course). Defects of current use of technology, the nature and scope of appropriate technology. Use of resources: energy supply and demand; metals and other raw materials, scope for reduced demand and for re-use; energy input to food production; 'organic' fertilization; protein supply a critical element. The nature of work; alternative methods of organizing society and industry; co-operatives, self-help schemes, small businesses and their needs.

TABLE 2. Year Two

Course	Hours Term 1	 Term 2	 Term 3
Energy conversion I (elec.)	15		
Energy conversion II (mech. & fluid)		30	
Measurement and instrum.	15		
Structure of materials	15		
Macro. props. of materials	15		
Intro. electronic engineering		30	
Production technology		30	
Design I			15[1]
Machinery for agriculture			30
Organization of production	15	10	
The natural environment	15		
	90	100	45
Engineering laboratory		75	
Design exercises (machinery for agriculture)		40	
Design exercises (mech. des.)		40	
Exercises (organization of production)		40	
		195	
Workshop practice		2 weeks after exams	

1. Design I (second-year course). Fitness for purpose: market surveys, specification, value analysis, figures of merit, 'well-conditioned' design, safety. Ergonomics: human proportions, comfort, strength, fatigue, controls for equipment, tools presentation of information to machine users. Noise: characterization and methods of reduction. Graphics.

TABLE 2. Year Three

Course

CORE
Resource engineering[1]
Design II
Intermediate technology[2]
Project (individual or group)

OPTIONS – at least four to be chosen including at least two from list A and one from list B

LIST A
Engineering thermodynamics
Fluid mechanics A and C
Transport
Electrical power and machines
Measurement and quality control
Water resource engineering *or* low-cost housing and development.

LIST B
Business studies I
Technology, industry and society
Food production
Foreign language

1. Resources engineering (third-year course).
Energy analysis: definition of system boundaries; energy in capital plant; energy in use; input-output energy tables; process analysis and measures of efficiency; application of energy analysis; techniques to the recycling of steel and the extraction and distribution of gas.
Energy supply: energy consumption and conservation; energy requirements and forecasting techniques; energy cost of energy supply; critique of principal short- and long-term technical options for power supply.
Production of materials: definitions of reserves; economics of extraction and distribution; international trade in materials; high energy materials; bulk materials and land spoilation; natural (agricultural) and synthetic materials; recycling of materials; case-studies of copper, gravel, fertilizers, wood and water.

2. Intermediate technology.
Traditional technologies, their strengths and inadequacies; history of industrialization in developing countries and its relationship with urbanization; the informal sector of urban economics; constraints upon, and defects of, traditional and industrial patterns of production. Requirements of a technology for rural development; characteristics of intermediate technology today; case-studies of, for example, rural transport and domestic energy supply in the contexts of particular countries, examining actual and available technologies, social and ecological constraints.

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Environmental engineering in education and practice: the emerging shape

Hassan M. El-Baroudi,
Dev R. Sachdev
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Summary

Recent developments in the comparatively young field of environmental engineering demonstrate the response of the engineering community to a range of national and global environmental concerns. It is the purpose of this chapter to review the educational and professional aspects of this field. Based on the review and findings, an outline of a new approach to environmental engineering is presented. This approach should serve to stimulate further discussion of what is, arguably, the most important current development in engineering education.

Areas of knowledge in environmental engineering

The environmental engineering field is characterized by a consistent objective: protection and improvement of the quality of the environment for the benefit of mankind. The required areas of knowledge have been subject to periodic modification (mostly expansion) because of the increasing intensity and diversity of human activities. The civil and sanitary engineers were the pioneer environmental engineers when environmental quality concerns were limited to safe water supplies, wastewater disposal and land drainage. Formal sanitary engineering curricula were introduced as graduate (or post-graduate) programmes and included public health engineering, water and wastewater treatment as the primary courses to be taken by all graduates. In most programmes a host of related science and engineering-science subjects became necessary: chemistry, microbiology, public-health sciences, hydraulics, hydrology, etc.

Sporadic efforts to introduce sanitary engineering as an undergraduate engineering discipline were not successful. Many engineering professionals and educators maintained that sanitary engineering was more of a professional training than a discipline (similar to that of public health) and that it should only be offered at the graduate (or post-graduate) level.

An interesting experience was the introduction of the undergraduate sanitary engineering programme at the University of Alexandria in Egypt in 1949. The programme spanned the last two college years and was offered to students who completed the requirements of the preceding three years of civil engineering. In these two years, courses such as water and wastewater treatment, water supply and sewerage, public-health engineering, microbiology, sanitary chemistry, and sanitary bacteriology replaced courses in structures, highway construction, coastal engineering and advanced reinforced concrete. The new department continued to suffer from lack of student enrollment and professional recognition. In spite of the technical support by the World Health Organization (WHO), the department was eventually reduced to a minor option in the civil engineering undergraduate programme.

Perhaps the first development in sanitary engineering was its definition as the water quality management portion in the field of water resources management (the use of 'quality' is significant). This was documented by Professor F. Pöpel in his assignment report to the WHO in 1965 (Pöpel, 1965). The assignment was to advise on sanitary engineering education and research needs in Egypt.

Professor Pöpel tailored his educational recommendations carefully to local problems (e.g. parasitic diseases, flies, shortage of water) and local aspirations (e.g. desert reclamation and industrialization). His major recommendations included:

> The main training in sanitary engineering should preferably be concentrated in the post-graduate courses, for engineers having some practical experience in municipalities, governments, ministries, or research centres.
>
> The undergraduate curriculum in civil engineering should include substantial study in all the following four subjects:
>
> a. Stream pollution control
> b. Water supply
> c. Sewage disposal
> d. Refuse disposal and city cleaning.

Influenced by water-scarcity problems in parts of Europe as well as in Egypt, Professor Pöpel suggested a list of primary and secondary subjects that sanitary engineers should study in each of the two water-resources management options, quality and quantity.

In other developing countries of the world, such as India and Pakistan, environmental-engineering education has been through an evolutionary process, guided by the needs of these countries. In India, civil and sanitary engineers initially played the traditional role of providing water supply and wastewater disposal systems.

Later on, the sanitary-engineering concerns became part of the broader field of public health engineering. A variety of environmental functions were assigned to public-health engineers at local, state and central levels. With India being afflicted by certain endemic diseases, greater emphasis was placed on courses in communicable disease control, environmental microbiology and malaria engineering. More recently, as India becomes more industrialized, new pollution-control technologies, and industrial waste management are being added to curricula on environmental engineering and public health.

The revolutionary developments of the 1960s and early 1970s in the scope of sanitary engineering in the United States were associated with widespread adoption of the broader name of environmental engineering by universities, societies and technical journals. If sanitary engineering was concerned with water management, the new environmental engineering dealt with, in addition, air-pollution control, solid waste management, radiological health, new sophisticated waste processes for new objectives of treatment, and with vaguely defined objectives of preserving fragile environments and maintaining ecological balances.

To meet these challenges, the graduate programmes in sanitary environmental engineering continued to broaden their curricular and research areas, for training the interdisciplinary environmental team of engineers and scientists. The recent remarkable growth in environmental engineering concerns can be appreciated by comparing the 'keyhole concept' proposed at the 1967 EEIB-AAPSE conference (EEIB, 1973) with the 'domains of environmental engineering' formulated in the AAEE-AEEP conference in 1973 (AAEE, 1973)[1]

In the 1967 conference, the environmental engineering curricula were represented by two concentric circles. Inside the core circle, there were chemistry, biology, social science, engineering systems and planning. In the other 'spectrum of curricula', there were water resources, air resources, sanitary or water-quality engineering, public-health engineering, radiological health and solid waste. In the 1973 conceptual illustration (AAEE-AEEP conference), there were three circles instead of two. In the core for 'major professional fields', there were air quality, water quality, industrial hygiene and solid wastes. In the first annulation, there were 'specialty areas' of chemistry, radiological, physics, safety, biology and noise. Finally in the outer 'fields with environmental concerns', a partial listing was provided as public health, fisheries, transportation, natural resources, construction, architecture, economics, law, planning, recreation, manufacturing and processing, mining, energy, and agriculture.

It is clear that environmental engineering needs and applications exist almost everywhere. Graduate environmental engineering curricula designed to meet the educational needs of these applications exist in an estimated 110 engineering schools in the United States. An excellent and highly informative reference on these programmes is the 1974 register co-sponsored by the AEEP and the AAEE (Klosky, 1974).

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[1] EEIB is the Environmental Engineering Intersociety Board; AAPSE is the American Association of Professors in Sanitary Engineering; AAEE is the American Academy of Environmental Engineers; and AEEP is the Association of Environmental Engineering Professors, which was AAPSE before a name-change in 1972.

For each programme the register provides the name, address and telephone number of the programme, chairman or resource person, a brief history and description of the programme admission requirements, course offerings, a list of core and associated faculty with brief professional sketches and research interests, the record of student enrolment and available facilities. From the reported admission requirements, it is clear that a bachelor degree holder in almost any engineering or science field, with a reasonable undergraduate record, can find the master's or doctoral degree programme that best fits his environmental and professional interests.

FACULTY QUALIFICATIONS

An interesting account of the areas of knowledge related to environmental engineering in the United States can be obtained by considering the qualifications of its own faculty. These qualifications were also furnished by the register which included 71 programmes, 2 of which were in Canadian universities. Of the 71 reported, 65 universities provided a complete degree record for all or most of their 412 core faculty members. Table 1 shows the discipline in which these faculty members had specialized for their bachelor, master and doctorate degrees. An arbitrary clustering of various degree titles is adopted as follows:

Civil engineering: includes degrees reported as civil engineering, and the few exceptions which specified the degree as in structures, construction, hydraulics, and hydrology.

Sanitary/environmental engineering: includes also degrees entitled water resources, hygiene, industrial hygiene, sanitation, environmental systems engineering, environmental/public/occupational/industrial and radiological health engineering.

Other engineering: includes mechanical, electrical, petroleum, engineering, engineering science, agricultural, geological, mining, irrigation, industrial, soil and systems engineering.

Environmental sciences: includes also sanitary science, water, chemistry, limnology, environmental-health science, sanitary chemistry, ecology, microbial ecology, environmental chemistry, aquatic biology, atmospheric chemistry, environmental microbiology, sanitary chemistry and biology, and radiological biology.

Chemistry: includes also biochemistry, geochemistry, and the following chemistries: organic, agricultural, food, nuclear, physical and analytical.

Life sciences: includes bacteriology, biology, microbiology, zoology, bo-

TABLE 1. Academic degrees held by core environmental engineering faculty (412 in 65 programmes)

Discipline	Bachelor		Master		Doctorate	
	No.	Percentage of total	No.	Percentage of total	No.	Percentage of total
Engineering	*(309)*	*(75.0)*	*(309)*	*(75.0)*	*(283)*	*(68.7)*
Civil	230	55.8	129	31.3	84	20.4
Sanitary/ environmental	12	2.9	145	35.2	172	41.8
Chemical	35	8.5	19	4.6	15	3.6
Other	32	7.8	16	3.9	12	2.9
Sciences	(85)	(20.6)	(66)	(16.0)	(78)	(18.9)
Environmental sciences	3	0.7	23	5.6	30	7.3
Chemistry	31	7.5	8	1.9	15	3.6
Life sciences	32	7.8	21	5.1	14	3.4
Other	19	4.6	14	3.4	19	4.6
Not-specified	(18)	(4.4)	(13)	(3.2)	(12)	(2.9)
None	—	—	(24)	(5.8)	(39)	(9.5)
TOTAL	412	100.0	412	100.0	412	100.0

tany, medicine, plant pathology, biophysics, plant physiology, veterinarian medicine, mycology, and veterinary biology.

Other sciences: includes physics, nuclear physics, mathematics, geology, soil physics, meteorology, oceanography, food, naval, military, computer sciences, then the social sciences of economics, business administration, urban planning, sociology and agricultural economics.

This mixture of faculty demonstrates the outcome of the efforts to provide the graduates with the education necessary for managing environmental quality. From the list, and the distribution shown in Figure 1, one can conclude that environmental engineering is the interdisciplinary engineering field *par excellence*. Also, the professionals who are contributing most to this field are the civil engineers. Finally, only 3.6 per cent of the total faculty has an undergraduate education that was environmentally oriented either in engineering or in science. This is due to the fact that environmental studies have so far been offered mostly at the graduate levels.

CONTENT OF PROGRAMMES

Considering the distribution of formal disciplines among environmental engineering faculty, it is possible to argue that the field of knowledge in environmental engineering is made up as follows: environmental (sanitary) engineering, 40 per cent; other engineering, 30 per cent; environmental sciences, 10 per cent; basic sciences, 5 per cent; social sciences, 5 per cent; individual options, 10 per cent.

If the environmental-engineering education is available only at the graduate (master's degree) level, then an engineer applying to the programme can be assumed to have already satisfied the 30 per cent of other engineering and 5 per cent of basic sciences. Consequently, the one-year graduate programme in environmental engineering can have the following distribution: environmental engineering, 60 per cent; environmental sciences, 15 per cent; social sciences, 10 per cent; individual options, 15 per cent.

These distributions seem generally acceptable and reasonably balanced. Since they are based on faculty qualifications, an attempt to identify future trends was carried out by the authors using a statistical analysis of the graduation dates of the faculty. One of the important conclusions is that the faculty with degrees in 'environmental sciences' are by far the youngest group. These sciences focus on monitoring and understanding the chemical, physical and biological phenomena in natural and polluted ecosystems, with the ultimate objective of preserving vital balances and desired environmental quality. It is consequently projected that the importance of environmental sciences will continue to increase in the education and practice of the environmental engineering field.

The practice of environmental engineering

As the need for safe water supply and wastewater disposal was recognized, the sanitary engineers had a stable market with reliable clients. The members of the sanitary-engineering and public-health teams were either self-taught or acquired additional training in the growing numbers of graduate programmes and schools of public health. In the case of sanitary engineering, the application of specific areas of knowledge was closely associated with, and dependent on, civil engineering construction, hydraulics, soil mechanics, and surveying. Its objective also fitted the philosophy of public service which has distinguished the civil engineering profession throughout its history.

In professional practice as in education, environmental engineering can broadly be defined in the context of historical needs and developments. One may assume that sanitary engineering was developed in response to two overlapping but distinguishable concerns. First was human health, and second was the quality of the surrounding environment. As human activities of urbanization and industrialization continued to grow, the simple water-related health aspects of sanitary engineering also grew and developed into public-health engineering. The recent intensification of industrial and urban activities has resulted in the development

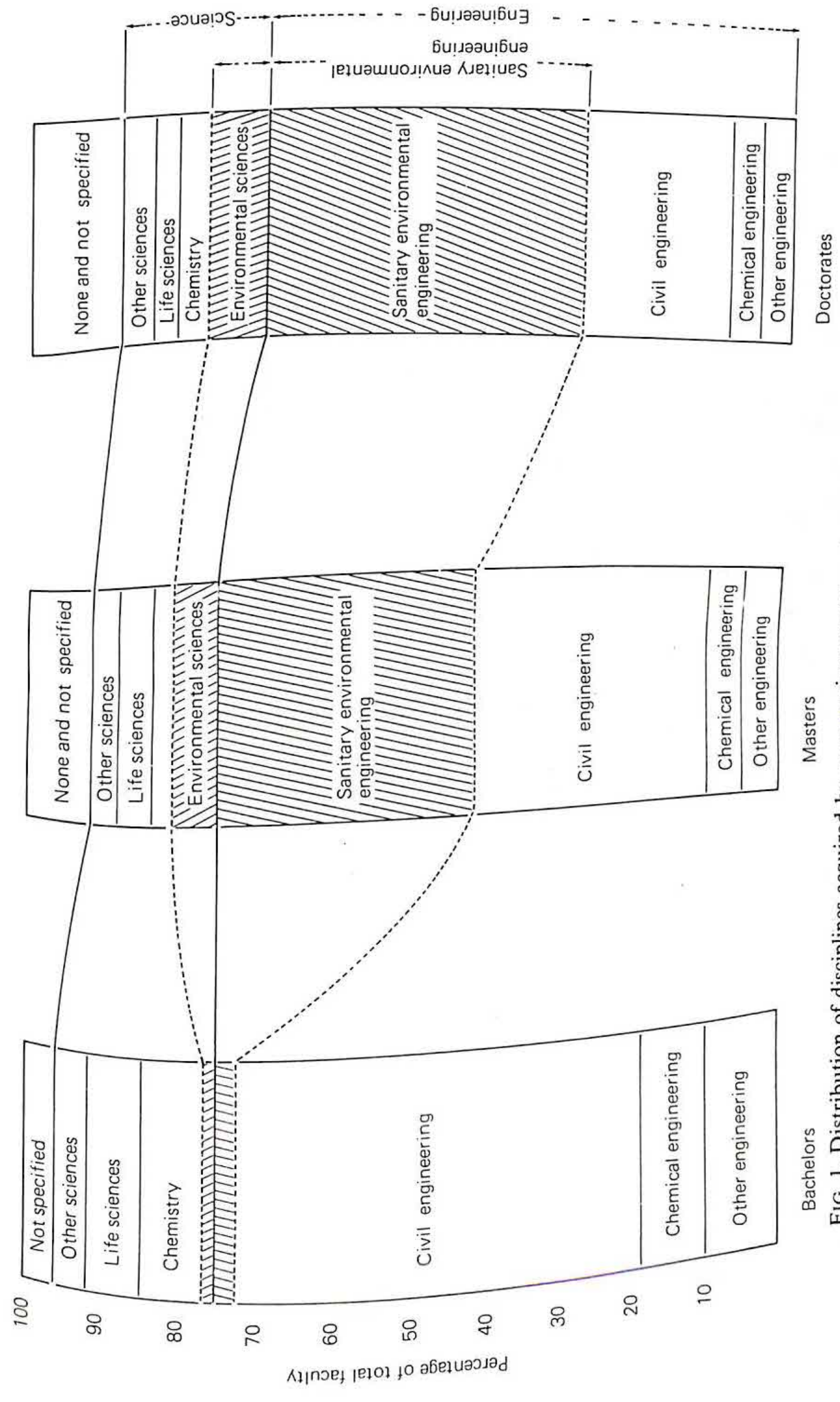

FIG. 1. Distribution of disciplines acquired by core environmental engineering faculty (412 in 65 programmes)

of the environmental aspects of sanitary engineering into what is now termed environmental engineering. Figure 2 illustrates this history.

THE ENVIRONMENTAL ENGINEER'S CLIENTS

A need can exist without being met, but a demand must have formal status. As in public-health engineering the demand for environmental engineering comes, directly or indirectly, from government (Oakley, 1978). In the United States, recent studies show that many environmental engineers will be needed in industry, all levels of government and in consulting (Middlebrooks, 1975; Middlebrooks et al., 1974). However, while the projections show the greatest need in industry and consulting firms, they assume a continuation of government support, and the implementation of relevent state and federal legislation. The latter includes the Solid-waste Disposal Act of 1965 and its amendments of 1970 and 1976, the National Environmental Policy Act of 1969, the Clean Air Act of 1970 and its 1977 amendments, the Water Quality Improvement Act of 1970 and its amendments of 1972 and 1977, the Pesticide Control Act of 1972, the Marine Protection, Research and Sanctuaries Act of 1972 and its amendments of 1977, the Toxic Substance Control Act of 1972, and the Drinking Water Quality Act of 1974.

Implementation of the goals and requirements of these acts will call for the expenditure of billions of dollars by the government and industries for years to come. Examples of these requirements are upgrading of all municipal sewage-treatment plants to the secondary level, replacement of ocean dumping of sludge by land-based treatment/recovery/disposal systems, introducing additional trains in water and sewage-treatment works for removal of organic and inorganic pollutants for which new standards have been set, extensive monitoring of waste streams and the environment surrounding them, and so on. These activities will provide many opportunities for environmental engineers and scientists in government and industry.

However, the driving forces behind this need are the national and local legislatures which strive for a certain quality of the environment within the total picture of the economic, social and national defence goals of the citizens.

THE ENVIRONMENTAL ENGINEER'S PROFESSIONAL ROLES

The co-operation of an interdisciplinary team of professionals and technicians is needed for the implementation of the national and local laws and regulations related to environmental protection. Other non-engineering professions have also crowned their practitioners with the 'environmental' prefix. As a result, in addition to the environmental

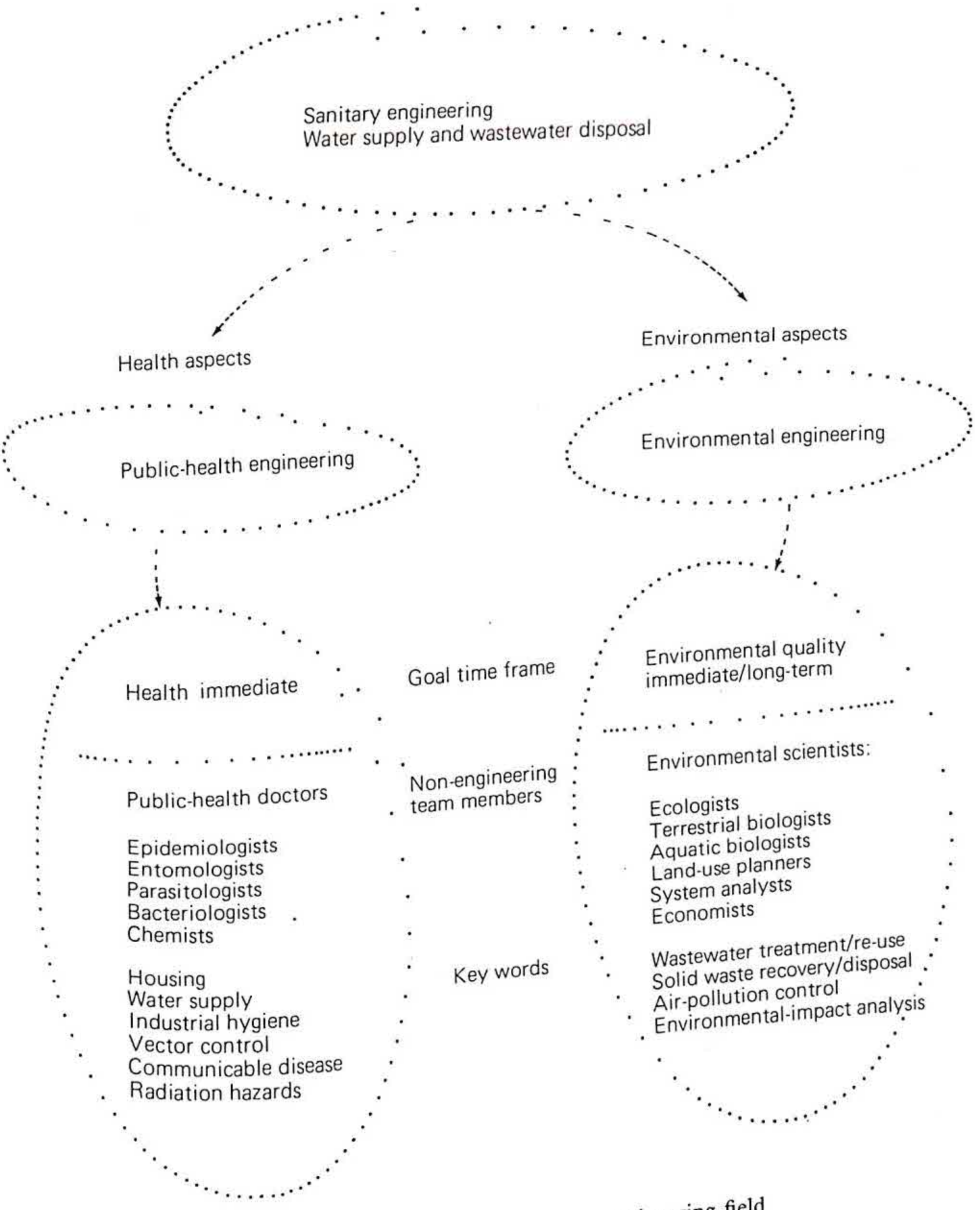

FIG. 2. Development of the sanitary-engineering field

engineer, we now have the environmental scientist, the environmental-planner, biologist, chemist and economist. The same distinction was adopted when the interdisciplinary team of engineers, doctors, nurses, etc., was formed in the field of public health. The scope of the work of the public-health team members had visible limits in time and space that were easily comprehended and appreciated by everyone, which matched human activities at home, at work, in the market place and recreation centres. The public-health effort was closely and immediately reflected in improved health, comfort and aesthetics.

For the newly formed environmental teams, the potential scope of work can be very broad indeed, in space and in time. Environmental concerns extend from the ocean depths to the depletion of ozone layers in the upper atmosphere. Threatened wild-life habitats are creating environmental concerns about possible impact that may be extremely long term or even unknown.

Rescuing 'Space Ship Earth' from the destruction of its fragile ecosystems is the ultimate goal of involved scientists, engineers, legislators and others.

By the nature of the engineering profession, only in the stage of developing and implementing a plan of work with a clearly defined scope, can the environmental engineer become a viable member of the team. The following are examples of such work carried out in the United States partly in compliance with environmental laws: siting studies; environmental impact analysis; water and wastewater management studies; solid-waste and resource recovery engineering; and air-pollution control.

Siting studies

In these investigations, the environmental engineer is ideally a member of a team. The team may include, where appropriate, land-use planners, geologists, civil engineers, socio-economists and other specialists, as well as the engineers responsible for the implementation of the project. Within the study region, a list of potential sites or areas is first drawn up on the basis normally, of general economic feasibility. With further analysis of the published site data, and micro-political factors, and through the application of exclusion, avoidance and preference criteria, some potential sites can be eliminated. The remaining sites, called the 'candidate sites' are subsequently subjected to detailed investigation to finally select the preferred site. The site-selection process includes the following steps, where appropriate:

Step 1 – project summary: land requirements; raw materials and finished products, if any; waste streams (solid, liquid, and gaseous wastes), their quality and generation rates; applicable effluent criteria, water-quality and air-quality standards; federal, state and local licensing requirements.

Step 2 – site specific data collection: soil characteristics including geology and hydrology; water quality and quantity to meet the project needs; ambient air quality; zoning and landways use ordinances; access roads/rail.
Step 3 – environmental impact of the project: air resources; water resources; terrestrial ecology; land uses; socio-economics.
Step 4 – cost estimates: approximate cost estimates for each candidate site are prepared.
Step 5 – ranking analysis: based on the information developed in steps 1 to 4, criteria for ranking analysis are established. The most suitable site is selected based on the results of this analysis.

Environmental-impact analyses

Until recently environmental considerations were unperceived or ignored in making decisions concerning the establishment or location of an industry, utility or public facility. Typically, the major thrust used to be on economic evaluation and engineering-feasibility studies. This is still the case in many countries. However, in countries where new procedures are demanded by legislation or clients, environmental criteria have had to be applied alongside the traditional economic, social and technological criteria.

An 'environmental impact analysis' is the study of probable changes in the environment which may result from a proposed project. The preparation of an 'environmental impact statement' (EIS) for a proposed project is an interdisciplinary team effort by environmental engineers, biologists, ecologists, chemists, sociologists, economists, planners, architects, and any other specialists whose expertise is relevant.

The environmental impact statement is a full disclosure document which discusses all significant impacts on the quality of the human environment. It is normally circulated to agencies, citizens, and organizations who might be affected. Public participation should be encouraged through open hearings, and modifications to accommodate public concerns should generally be expected.

The following items are generally covered in an environmental impact statement: (a) description of the proposed project; (b) the relationship of the proposed project to land-use plans, policies and other regulations of the affected area; (c) the probable impact of the project on the area's environment – this will include short-term and long-term impacts (the impacts discussed will be on water resources, air resources, land use, terrestrial ecology, and the social and economic infrastructure); (d) any adverse environmental impacts which can be avoided; (e) alternatives to the project and their impacts; (f) any permanent commitment of resources in the project; (g) mitigation measures which are proposed to minimize the adverse environmental impacts; (h) secondary or indirect consequences which are triggered from the primary impacts such as mitigation of population due to increased employment potential which in turn will increase pressure on the area services such as water supply, schools, fire protection, police protection and other social and economic activities.

Water and wastewater management studies

A water and wastewater management study seeks an optimal system of water supply, water use and re-use, and wastewater treatment and disposal. Treated water must meet the quality and quantity demands of its intended use. Treated wastewater from the facility must meet effluent criteria and receiving water-quality standards. Treatment in both cases, therefore, is related to quality needs and not to absolute standards which may be unnecessarily expensive.

The environmental engineer plays the leading role in these studies and draws help, where necessary from the mechanical, industrial and process engineers who possess specialized experience of the various unit operations and processes in the project. The studies are likely to include the following tasks:

Development of mass flow diagrams of water use and wastewater generation. Each system which uses water or generates wastewater should be identified. The average, maximum and minimum quantities of water and wastewater should be determined.

The identification of treatment systems to produce effluents conforming to applicable effluent and water-quality criteria. The study of alternative treatment concepts including the possibilities of re-use or waste reduction by mixing two or more waste streams that will neutralize some pollutants.

The selection of the most cost-effective and environmentally acceptable treatment alternative. The capital, operation, and maintenance costs of each alternative should be determined. The system reliability, and adaptability to variations in influent characteristics should also be considered while making the selection.

Solid-waste and resource-recovery engineering

The traditional engineering aspects of solid-waste management have been the determination of quantities, composition and storage methods at the source, design of collection and handling systems, and final disposal on land with or without volume reduction by various means.

Public-health ordinances and environmental requirements can regulate every stage of solid-waste handling. Various ways of reclaiming material and energy from solid wastes have been adopted for economic reasons in many countries. Examples of such recovery operations are separation and salvage at the source, composting of organic wastes, repulping of scrap paper, production of fuel gas by anaerobic digestion, and recovery of the heat of combustion in refuse incinerators.

Until recently, no significant reclamation activities existed in the United States even though such operations were successful in Europe, Japan, India and elsewhere. Several factors have forced the emergence of the new resource-recovery technology in the last decade. They include the sharp rise in energy costs, the stringent environmental regulations affecting final disposal, and the development of new conservation awareness and environmental ethics that discourage the wasting of resources on general grounds. Resource recovery in the United States is spreading in the form of central facilities for solid-waste shredding, separation and a variety of conversion processes.

Extending the objective of solid-waste management from safe disposal to reclamation of energy and material values is proving to be a highly complex challenge from the technical and institutional aspects. It is generally conceded that the utilization of complex technology requires the participation of private industries in operation or ownership. Implementing reclamation technologies calls for sizable investments which are financed on the basis of contracts with generators of wastes and purchasers of reclaimed energy and materials. In these activities, the environmental engineer is a member of a large team of other engineers, planners, investment brokers, economists, laywers, politicians, marketing analysts, and contract administrators. The role of the environmental engineer is most visible in conducting solid-waste surveys, development and evaluation of collection, transfer, recovery and disposal alternatives and the selection of the conceptually most cost-effective system.

Air-pollution control

Various industrial processes, electric generating stations, and incinerators of municipal solid waste or wastewater sludge emit pollutants such as suspended particulates, sulphur dioxide, oxides of nitrogen, carbon monoxide and other gaseous emissions, depending on the constituents of the process raw materials. The federal, state or local air-quality control regulations specify the allowable pollutant concentrations in the gaseous emissions. These criteria are established to protect public health and welfare and take into account the maintenance of a desirable ambient air quality.

The environmental engineer plays a leading role in air-pollution control and seeks assistance from other disciplines such as chemists, industrial and chemical engineers in performing the following tasks: (a) identifying the pollutants and their concentration in the emissions; (b) evaluating the impact of these pollutants; and (c) evaluating alternative control techniques and recommending the most cost-effective and environmentally acceptable alternative.

Proposed functional organization

Having reviewed the experiences and features of environmental engineering education and practice, the stage has now been reached to propose guidelines for the future. It is noted that recent developments in the field have occurred rapidly in response to the environmental-pollution crisis. Considerable progress has been made in a short period, but a basis is needed for planning future developments. The proposed scheme is based on three assumptions:

The work of the environmental engineer arises in association with, and in consequence of, other engineers. The prime concern of the environmental engineer is the reconciliation of conflicting human goals of material comfort and progress while conserving resources and environmental quality.

The environmental concerns will vary with time and place. Consequently it is proposed that the work of the environmental engineer be client-oriented rather than problem-oriented, e.g. air pollution, solid waste, and so on.

The education and experience of the environmental engineer must also reflect the responsibilities and interests of the client sources. Only if skills in environmental engineering match the needs of the subgroups of clients will the engineers develop the close understanding and mutual confidence which provide the basis of all good professional practice.

Figure 3 sets out the proposition and reflects these assumptions. Around the outside of the diagram are six fields of expertise. The first two are concerned with research, monitoring and prediction. The relevant disciplines are a range of pure and applied sciences which, brought together for the purpose of professional education and training, we can call environmental engineering-science, or simply environmental sciences.

The industries in the centre of the diagram have been divided into the three stages of 'extractive', 'basic' and 'conversion'. Directly related to and serving these are the areas of industrial hygiene (protecting the worker inside the industry) and waste and water processing (protecting and serving the citizen outside the industry). These areas we refer to as industrial environmental engineering.

At the base of the diagram are the urban or municipal communities, small and large. The concerns here are water supply and waste disposal, and the general problems of public health which involve the environmental engineer and his colleagues in other professions. These two areas of expertise we refer to as municipal environmental engineering.

It is unnecessary to emphasize the extent to which these various environmental engineering concerns impinge on each other. The arrows in the diagram indicate some of these repercussions and the importance of

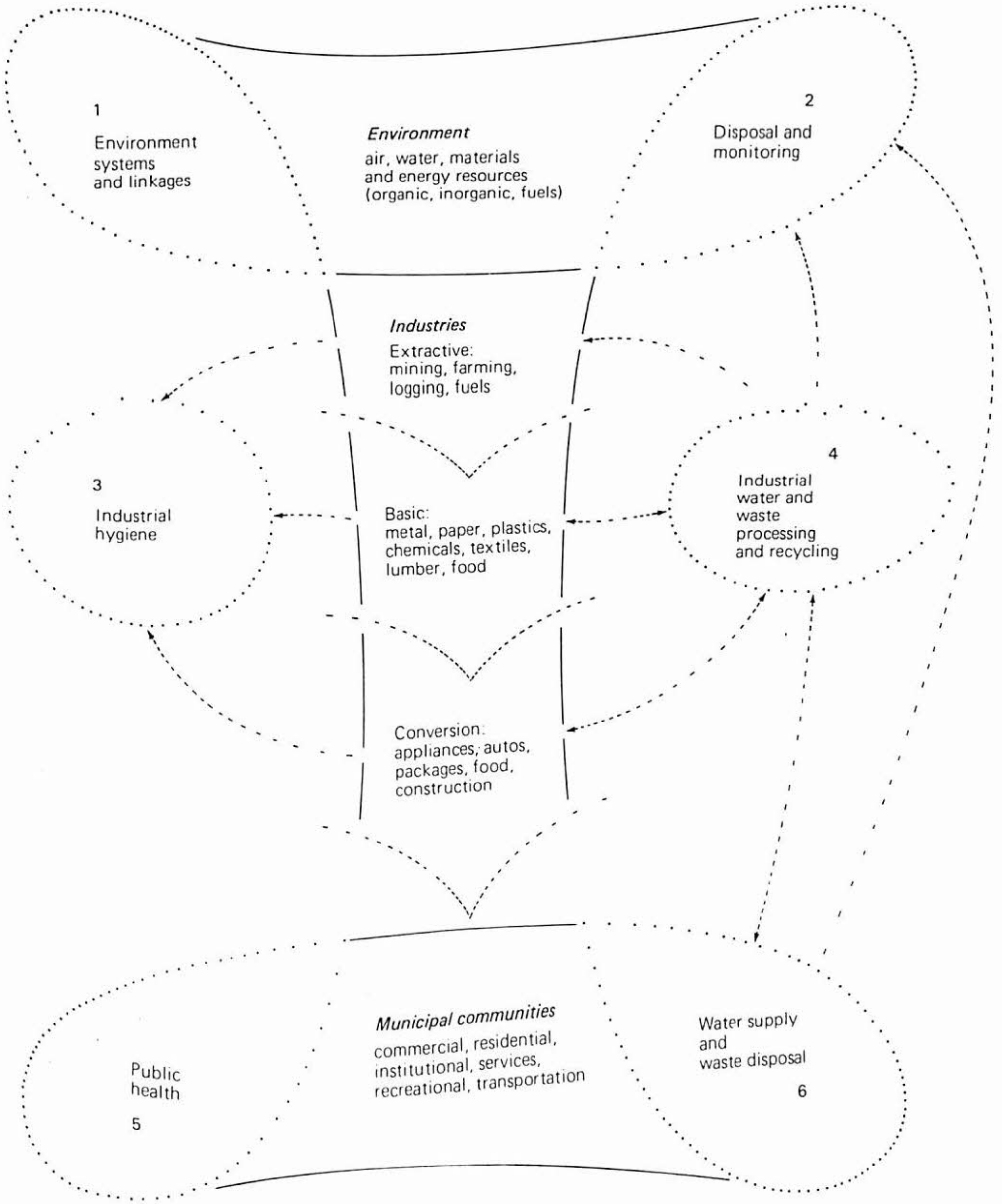
1
Environment systems and linkages
Environment
air, water, materials and energy resources (organic, inorganic, fuels)
2
Disposal and monitoring
Industries
Extractive: mining, farming, logging, fuels
3
Industrial hygiene
Basic: metal, paper, plastics, chemicals, textiles, lumber, food
4
Industrial water and waste processing and recycling
Conversion: appliances, autos, packages, food, construction
Municipal communities
commercial, residential, institutional, services, recreational, transportation
Public health
5
Water supply and waste disposal
6

FIG. 3. Environmental engineering concerns in the context of human activities

broad education and effective intercommunication throughout professional life.

Figure 4 focuses on the professional structure derived from Figure 3. The significance of environmental engineering science is that it not only functions directly, in approaching environmental problems at a high level of generality, but also provides the matrix of knowledge applied in and through the other two domains.

Table 2 extends the concept of the three domains into further detail. More important, it deduces the undergraduate preparation for these domains as regards common core studies, departmental affiliation and the areas of knowledge in which the respective specialists will have primary expertise. And, reflecting the aim of client-orientation, it relates each domain to the groups of employers whose interests it will serve.

Perhaps the reorganization proposed in this chapter will be put formally into effect – as a deliberate step, in one country or another, by government initiative or by professional bodies. In many countries, it must be agreed, intervention of this kind is legally not feasible or administratively out of tradition. Maybe changes are happening anyway, here and there, because professional groups, like all organisms, are subject to the imperatives of evolution, adaptation and survival. Either way, an awareness of conceptual shift lubricates the process of change. If this chapter has contributed a measure of self-awareness to the environmental engineering profession and a recognition of its destiny, the authors' purpose will have been achieved.

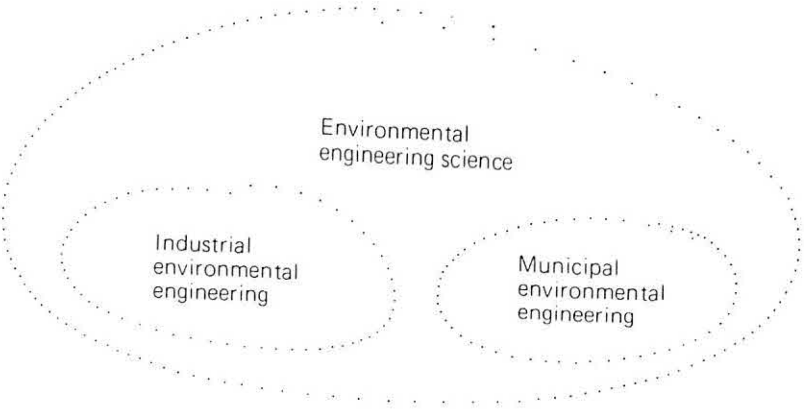

FIG. 4. Proposed three domains of environmental engineering

TABLE 2. A proposed reorganization of the environmental engineering field

Item	Domains of environmental engineering		
	Environmental engineering science	Industrial environmental engineering	Municipal environmental engineering
Primary student background	Science	Chemical engineering	Civil engineering
Departmental affiliation	Science department, engineering department or interdisciplinary centre	Department of chemical engineering	Department of civil engineering
Degree offering	Bachelor, master, doctorate	Master, doctorate	Master, doctorate
Common core preparation	Environmental biology (ecology), resource development and utilization, environmental quality parameters, environmental impact analysis		
Primary areas of knowledge	Biological effects of pollution, management for pollution control, analysis for pollution control, ecosystems modelling	Industrial hygiene, industrial-pollution control, technology for resource recovery, water processing for industry	Public health engineering, water treatment and disposal, municipal refuse disposal, air-pollution control
Primary employer	Federal and state governments plus consulting	Industries plus consulting	State and local governments plus consulting

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The organization of process: some notions and models

David Brancher

Introduction

It is not uncommon for educators to divide their descriptions and evaluations of education into 'content' and 'process'. 'Content' is usually taken to mean the body of knowledge and skills which students are expected to acquire. 'Process' generally means the activities whereby students penetrate, comprehend and apply such knowledge and skills, whether under coercion or due to innate motivation.

It is also not uncommon to find teachers in higher education who are more aware of content than they are of process. If they use the English language this is reflected in their choice of words. Instead of referring to content as 'syllabus' (derived via modern Latin from ancient Greek and meaning 'a list of headings') some teachers use the word 'curriculum'. But curriculum (derived indirectly from the Latin for 'running') is properly used to describe the activity and effort, the process, through which the syllabus is experienced by the student. The distinction is crucial and the tendency of teachers to dignify syllabus (or content) with the potency of curriculum (or process) has sterilized many a debate on curriculum development.

The idea that the cultivation of process is more important than the transfer of content, is probably as old as Socrates. It means that the fruits of inquiry by others are sometimes less valuable than the ability to inquire for oneself; that active learning is preferable to passive learning because it is habit-forming, does not depend on formal teaching and can therefore continue through life under self-direction. And yet, although many educators pay lip-service to the importance of process, they continue to advocate and describe courses using only lists of the knowledge held by teachers.

This criticism, well-worn though it may be, serves to illuminate a problem of academic organization. For just as the academic may see curriculum as little more than a list of knowledge, he may see academic organization as little more than providing a list of the people holding such knowledge. Of course, funds may not allow the immediate recruitment of every member. But as each arrives he or she is expected to drop into the slot provided in the grand design. Click!

It is perhaps not surprising that so formalistic an approach can sometimes be found among engineering academics; and yet it appears widely in universities. In all the fields of higher education, however, it is at its most damaging in environmental education. There are four reasons: (a) environmental education impinges on a wide range of subjects; (b) a high level of integration is required before the knowledge and skills within these subjects can be put to good use; (c) it is necessary for this integration to be dynamic and creative, as new knowledge and insights emerge from specialist sources and as new environmental problems and opportunities emerge in the real world; and (d) many students and even faculty are nevertheless reluctant to engage with subjects they perceive as extraneous.

THE HIDDEN CURRICULUM

Let us take the last point further. We can expect to see some differences, in matters of motivation, between graduate students taking courses in environmental engineering (in all its sub-specialties) at master's and doctoral level, and undergraduate students receiving courses in environmental subjects at what is sometimes called appreciation or awareness level. As examples of the latter we can think of civil-engineering students studying landscape architecture; chemical engineering students taking a course in fresh-water ecology; agricultural engineering undergraduates studying the effects of certain pesticides. Whereas the graduate students have chosen a branch of engineering directly concerned with 'the environment', the undergraduates are less committed; perhaps uncommitted. They may have rigid preconceptions as to what engineering comprises, and even resent an additional demand on their time and energy.

We must not however be too categorical about this. Problems of motivation can arise at any level. Environmental studies make heavy demands – for example, the need to transfer models from one field to another, to balance measurable phenomena with subjective and value-weighted considerations, and to take some instruction on trust until its relevance is later established. The school must recognize these demands and anticipate them in its scheme of organization if it is to achieve educational success.

If there are problems of motivation among undergraduate students we are more likely to find them where subjects are being taught by teachers who are not engineers. Let us be clear that this is only a matter of probability. Some non-engineers, teaching engineering undergraduates, are rewarded with keen attention and hard work. And some engineering teachers face problems of motivation. But the non-engineers have a handicap which sociologists explain in terms of self-reference and role-models. Most students who intend to become engineers refer themselves to people who already are engineers. These people become their role-models; the students take their attitudes and values (and maybe other elements of personality) from the engineers they meet in the school. Parallel tendencies can be found in schools of architecture and medicine. This is an aspect of what has been called 'the hidden curriculum'. No one concerned with interdisciplinary studies should underestimate its effect.

The implication is not that engineering schools should be staffed only by engineers. The loss would be great. It does, however, mean that the leaders of the school, indeed every engineer in the school, should realize just how important it is that they show students, openly and in more subtle ways, that subjects outside the mainstream of engineering science are important and interesting, and that their non-engineer colleagues are relevant and interesting people. They can do this in many ways. They can teach together with the non-engineers where practicable; discuss the complementary curriculum with students; insist on parity of effort and assessment within it; avoid any suggestion that there are fringe subjects in which lower standards will be tolerated.

THE NON-ENGINEER TEACHER

The recruitment and continuous motivation of teachers who are not engineers is a difficult matter. The whole tradition of higher education in many countries is that status and career depend on specialization. Specialized research, moreover, demands an environment of specialization – frequent contact with fellow specialists, certain library resources, the teaching and supervision of advanced students, sometimes special equipment and laboratory facilities.

In what is primarily an engineering school it is not often that such conditions can be met for the non-engineers. It is not often, also, that non-engineers have career prospects which match those of the engineering faculty. This is not necessarily because the non-engineers are regarded as subordinate or peripheral. It is often because their subjects are not regarded as central enough to justify a designated senior post, for example at the level of full professor, reader or *dozent*. The problem of professional licence may come into this; to some it may seem inappropriate to have a professor, in a school of engineering, who is not an engineer.

The problem may however be transient, and ultimately be resolved by academic development. A good example of this comes from architectural education. This field of study was, until recently, in some Western countries, based in colleges of art and independent of engineering and science education. As the need was recognized for teaching in acoustic and thermal fields, physics teachers were recruited to the teaching staff. Some of them, having the wisdom to seize an opportunity, abandoned thoughts of a career in academic physics and devoted their teaching and research to the application of physics and systems modelling to building performance and design. As their experience grew, so did their subject, and it is now possible to make a respectable career in architectural or building physics. It is not difficult to foresee similar career opportunities in non-engineering subjects from which environmental engineers already draw information and technique.

If opportunities such as these are missing, and not seen by the non-engineers to be in prospect, the inevitable will happen. Active and ambitious staff will treat environmental education as a stepping-stone and return to their original specialisms at the first good opportunity. Only the less capable will remain and the chances of creative interdisciplinary teaching and research will therefore dwindle.

RESEARCH

Throughout higher education, and particularly in the applied and professional fields, the term 'research' seems to be used loosely, to cover a range of recognized activities. It can, of course, mean original theoretical or experimental work, leading to publication in refereed journals of scholarly status. It can mean disciplined speculation and comment, sometimes on matters of policy and professional affairs, published in periodicals with a more general readership. Again, it is usually recognized that academics may have to spend some of the time allocated to research, in reading and consultation which will enable them to teach new subjects or to supervise research which is beyond their previous experience. Sometimes this can involve originality and developments of great value, when knowledge and technique are translated from one field to another to yield new insights and open up new opportunities in professional practice. This also may be referred to as research. And the term may be used even more loosely to cover activity outside the university – consulting work with firms and official organizations, and voluntary service on advisory and research councils of many kinds.

We have already remarked that, generally in higher education, it is pure research and publication in scholarly journals which brings the greatest prestige and rewards (and reward can cover anything from security of tenure in a junior post, to the granting of a chair). There are two reasons for questioning this emphasis. One is that some people, highly intelligent and competent, lose their interest in pure research at a certain stage in their careers. Some, indeed, may be unfitted for it at any stage, having qualities which can better be used in some of the other activities we have mentioned.

The second reason for questioning the traditional priority is central in many of the issues and problems of the environment and in environmental education. To use the word 'environment' is to recognize the existence of certain values and the concern which surrounds them. It is moreover a sign of interest in what an economist calls 'externalities' and in the transactions between any system and all that may be changed, and cause change, around it. The transactions may be physical, biological, aesthetic, social, economic, commercial, psychological, political. It follows that when a group of people from a mixture of disciplines are responsible for environmental improvement or for environmental education, they should be ready to use the knowledge and insights of all the specialties they represent.

Specialists research is unlikely to bring this about. Indeed it may prevent it. Emmelin (1975) questions

> the assumption that involvement in research makes scientists particularly well read in a wide enough field. The necessary specialization... may be so time-consuming that the broad reading of a teacher in a general environmental programme becomes impossible.

There is another assumption which must be challenged. The idea that conventional academic research is essential to good teaching, that active researchers are more likely to be good teachers, is part of the conventional wisdom in universities. As Flood-Page (1972) has pointed out there is no evidence for this widely treasured contention. Indeed, its existence, unsupported by research, is a denial of academic values. Voeks (1962) carried out a study at the University of Washington, using two samples of 405 and 193 teachers respectively, in a span of 28 departments. She concluded that research and effective teaching 'simply are not related in any apparent way'. Gafni and Waks (1978) more recently surveyed the situation at Technion. After studying the research performance of 259 teachers and 16,599 questionnaires which rated students' assessment of teaching effectiveness, they concluded:

> the substantial negative correlation coefficient between teaching and research obtained when grouping teachers by rank and faculty indicate that, on average, teaching and research achievements somewhat oppose each other.

The integration of knowledge is not easy to achieve among people who have been conditioned by a background in single-discipline and specialist study. It requires a learning culture – a social environment in which curiosity, the exchange of knowledge, intellectual excitement and eager discussion are normal. In other words a culture must be established, among teaching and research staff, which is a model of the atmosphere the best educators seek to develop among undergraduate students in environmental studies and environmental engineering. The establishment of such a culture, and its maintenance against the forces of specialization, are the prime tasks of the academic administrator.

The tangible results of a ferment of interdisciplinary learning may take several forms: (a) new case studies and exercises for students; (b) games, simulations and role-play exercises; (c) design exercises requiring interdisciplinary supervision; (d) field studies which bring together students from different undergraduate programmes; and (e) ideas for problem-based research and arrangements for developing contact between academics and practitioners.

Academic systems have a great deal of inertia, for a variety of reasons. It is not easy for an emphasis to change, for new priorities to be appreciated by members. This means that if deans, heads of departments and other senior administrators are to succeed in developing interdisciplinary teaching and research and in giving it precedence over conventional and specialist studies, they may have to be particularly explicit in what they say to new and existing colleagues. It is even more important that their decisions – in matters of tenure and promotion for example – reinforce their verbal leadership. 'Actions speak louder than words.'

A final point needs to be made. It is customary to criticize engineers for their supposed ignorance in academic fields outside their own. This may sometimes be justified. But what seems prevalent is a tendency among non-engineers to assume that 'interdisciplinary' means that the engineers must make all the effort to achieve a broader outlook. It is probably fair to say that the success of interdisciplinary teaching and research in environmental engineering depends to a large extent on the ability of non-engineers to learn some of the essentials in both the theory and the practice of engineering. In selecting non-engineers the administration should look for this readiness, while ensuring that it is responded to by engineering colleagues.

SOME CRITERIA

Keeping this discussion in mind let us set out some criteria by which the organization and leadership may be judged, in a school of engineering concerned with environmental education and training. Some of the criteria apply to structure and we shall consider some models below. Others are a matter of quality – the style of leadership, the attitudes of staff, the expectations of students.

The two influences are of course compounded. But whereas the implementation of a particular structure can, and in fact usually does, influence quality, it is seldom that high-quality people can overcome the disadvantages of an academic structure which is basically obstructive to the development of interdisciplinary teaching and research. Here are some questions:

Does the organization of the school and the system of courses ensure that engineering students recognize environmental subjects as within their 'territory' or frame of reference and impinging on their future role as engineers?

Does the system enable students to have spontaneous informal contact with environmentalists who are not engineers, and stimulate the use of educational resources?

Are the engineering teachers recruited to the school at least partly on their basis of their interest in the environment? Are they held to this commitment through joint activity with non-engineer colleagues?

Are the non-engineer members of staff recruited partly on the basis of their interest in engineering? Are they offered chances of self-fulfilment and promotion which are no less than those of their engineer colleagues? Is the promise kept, and shown to be kept?

Does the structure of the school, and the management of its time, oblige staff to engage in interdisciplinary activity as a prime responsibility? Is this activity programmed, so that a momentum is built up and maintained? (Here one can think of interdisciplinary seminars required of each member on fixed dates, attended by all colleagues; case studies or simulations to be written, and tried with students, by an agreed date; an agreement that a particular individual will spend his disposable time for a given period in studying a discipline complementary to his own, to meet a new teaching requirement.)

Is a record kept of each staff-member's contribution to interdisciplinary learning in the school, so that this can be given greater credit than specialist research and publication? Is this record discussed constructively with each member, say once a year?

Are the organization and the procedures within it flexible enough to be modified as mistakes are seen and new developments become necessary?

Some models

Keeping these criteria in mind let us now consider some models of academic organization. They have been taken from direct observation in a range of institutions which will not, however, be named. There are two reasons for this. The first is that, as with all models, reality has been simplified so that the essentials can be seen. If the sources were to be named it would be necessary to go into unnecessary detail and to report changes which have since occurred. The second reason is that some individuals might be upset by what they took to be criticism, however constructive the comment was intended to be. The models, then, should be seen as 'verbal line-diagrams', into which the reader's own experience can be projected. In every case the model is of a teaching arrangement or form of organization set up for environmental education. The title given to each model is no more than a label which can be used in subsequent discussion.

SERVICE TEACHING

This occurs generally in higher education where specialist departments, having degree programmes of their own, offer courses or sets of lectures to students in other departments. The content of this instruction may be taken unchanged from the service department's normal work with internal students; or it may be specially devised to meet the needs of the students, or the wishes of the staff, in the receiving department. Service teaching occurs probably in every university and requires no further description.

This type of arrangement has a number of advantages, some of which are a matter of expediency. It is generally a cheap arrangement, requiring no special appointments, and can sometimes be used to soak up surplus capacity in the assisting department. It is reasonably flexible, because new service arrangements can be made each year, but this means a lack of continuity. For example the teacher providing the service one year (and perhaps learning how better to tackle this often difficult form of teaching the following year) may be replaced by a colleague when the second year arrives. In conventional service teaching the individual continues with specialist research in his own department and has, of course, undisturbed contact with fellow specialists.

On the other hand, the arrangement does not in itself encourage interdisciplinary research, does not provide opportunities for students of two disciplines to work together on common problems, and reinforces the engineering student in what might be a dismissive attitude to subjects which are not perceived as part of 'real' engineering. Even if someone is asked to ensure that the service teaching is relevant to engineering, there is no guarantee that the service teachers will be obliged to respond to this guidance. On the contrary, their secure position in a specialist department unconnected with engineering, and the incentives which operate in that department, may ensure that the service teaching has a low priority among their various assignments.

SERVICE DEPARTMENT

This is a development of the above, whereby the department is set up within a faculty, without undergraduate students of its own and having service teaching to other departments as its prime function. The arrangement is commonly found in some large technical universities, where departments of mathematics and physics may exist in faculties of engineering, for the sole purpose of serving the undergraduate needs of engineering students. We may also find cases where a single department has been established for the purpose of offering a wide range of courses to engineering undergraduates in subjects such as environmental science, industrial psychology, management, law and economics.

Because service teaching is the prime purpose of such a department and because of closer physical proximity and staff relationships, the chances of integration are higher than they are where the teaching is provided by an external department with undergraduates and a research programme of its own.

A number of disadvantages remain, however, and the teachers in such a department may lack status in the eyes of some students and perhaps also members of the engineering staff. More important, they may feel that they lack status in the eyes of fellow-specialists generally in higher education; that they are second-class academics and that they should, as soon as possible, move on to departments specializing in their own disciplines where their career prospects may be better, or at least more conventional. On the other hand, the bringing together of such people can, in the right circumstances and with good leadership, lead to interdisciplinary teaching and research which is creative and a source of inspiration to students and colleagues. It is of course necessary to ensure that the service department has an establishment of senior posts comparable with that in the departments of engineering.

INTERNAL SERVICE TEACHER

What is described here is an arrangement whereby one or two non-engineers are based in an engineering department to carry out teaching outside the traditional mainstream of engineering studies. Each is expected to teach special courses or participate in interdisciplinary courses as necessary. Special research facilities are not generally available and there is seldom an opportunity for supervising research by graduate students.

Even more than in the first two models, success and failure depend on the quality of the individuals involved. It is possible for a teacher of outstanding ability to have an influence on the environmental interests of the engineering department, to achieve a special status within the department and even to carry out notable research. It must be said, however, that the chance of success is slight, and lower than the likelihood of the individual moving on to a more promising situation elsewhere.

NETWORK OF SERVICE TEACHERS

This is a rare arrangement whereby a number of individuals, as described above, are linked together in some form of department or quasi-department. This may mean that they occasionally exchange courses, or teach together to meet special requirements as they arise.

Clearly, the linking together of such people does provide psychological support and may mean that they have a senior spokesman who can look after their interests within the university organization. On the other hand, their membership in such a group may mean that they are less likely to be regarded as full members of the departments in which they teach.

INTERDEPARTMENTAL (OR INTERFACULTY) RESEARCH PROJECT

The college or university sets up a continuous research and consulting programme in a distinct academic area or (and this is more significant) concerning a local environment which throws up a range of scientific, planning and management problems. The latter might be, for example, a major river, lake or estuary; a decaying urban area or a mineral extraction programme. The environment in question becomes both a physical and an intellectual focus for undergraduate students who are drafted into the programme for interdepartmental preparatory courses and field studies; for staff undertaking problem-based research and consulting.

It is important that the project should have a wide variety of aspects, so that specialists from many disciplines can participate and relate their work to that of their colleagues. It is important also that it should be of fairly long duration – perhaps four or five years is the minimum.

This is necessary so that experience in undergraduate courses can be applied to making such courses educationally more effective in subsequent years; so that informal staff contact can lead to formal collaboration; so that experts outside the university can be attracted as advisers and critics; so that the programme as a whole can gather momentum, attract financial support and commissions from relevant government departments and agencies and generally add to the status of environmental education within the university.

There is little that can be said against such a model. It need not be expensive; in fact it may mean no additional costs, apart from those of a co-ordinator to ensure that collaboration between departments takes place on every possible occasion, to carry experience forward from one year to another and to represent the project outside the university.

RESEARCH INVOLVEMENT PROGRAMME

Under this arrangement undergraduate students have part of their time set aside with the status of a course, normally in the later years of their studies, so that they can participate in research or consulting work within the university or outside. The programme unit collects and negotiates offers of involvement from professors and research teams within the university, and from city departments, environmental agencies, special interest groups and research institutes outside the university. The opportunities are listed and briefly described, and made known to students when the time comes for them to apply for the positions of their choice. Credit is given for the work done by students, and both the students and their sponsors report back to the programme unit at the end of the attachment.

Some examples of such participation are: a civil-engineering student spending one day a week doing a survey of pedestrian movement at a traffic junction, which the city engineer needs but for which he does not have enough staff; a chemical-engineering student carrying out a study of toxic fume levels in local factories for a trade union which has no scientific staff; an electrical-engineering student working in the research laboratory in the university's department of biology, helping to devise equipment for the rapid analysis of water samples as part of an environmental monitoring programme; two students from mechanical engineering and one from production engineering working together, under the direction of the university's plant engineer, on ways of reducing the university's energy costs. As in the preceding model, a great deal depends on the quality of the faculty and students, and the enterprise of the programme co-ordinator. It is important that the students should not be treated as cheap labour and given menial or repetitive tasks. In every case the co-ordinator should establish beforehand what educational purpose is likely to be served by the proposed attachment, and the extent to which the proposed supervisors are committed to making the experience educationally a success. Where the students are of high quality and the programme is well co-ordinated, a significant number of people inside and outside the university may gain substantial assistance in their work and sometimes a fresh view of the problems being tackled.

It must be said, however, that the educational advantage of such a scheme can only be stated in general terms. Because of the wide range of individual experiences, and the ways in which these may change from one year to another, depending on the offers made by sponsors, it is virtually impossible to predict the factual information and skills which students will acquire. The benefit lies above all in the process of working closely with committed professionals on problems of immediate importance.

ACTION RESEARCH WITH EXTERNAL SPONSORSHIP

In some ways a larger-scale version of the above, this model applies only at the graduate level. Students (with good undergraduate qualifications and possibly several years' experience after graduation) are sponsored by employers or potential employers in undertaking interdisciplinary research within the university on a problem selected by the sponsors. In some cases, the students may be staff members of the sponsoring organizations, on secondment for the duration of the research.

In other cases the research students may be prospective employees of the sponsoring organization. In both instances the organization may see the programme as an opportunity for preparing people for senior positions. The sponsoring organization pays all or part of the costs of the student, and contributes to the running costs of the programme. In exchange for this the university undertakes to make its faculty available, as necessary, for advice and supervision. The co-ordinators maintain close contact with the sponsoring organization to ensure that the investigations point directly towards the particular problem with which the organization is concerned. It is normal for a senior and suitably qualified member of the organization to act as joint supervisor of the students, for the same reason.

The advantage of a scheme like this is that environmental research is kept firmly relevant to live problems of some urgency; that the value of the higher degree is established by its connection with such problems; that links are built up between organizations and universities to the benefit of both. The development of such a scheme depends, as in previous models, on the energy and ability of co-ordinators. It depends less, however, on the quality of its students because in most cases the sponsoring organizations are expected to find people of the necessary intellectual capacity and motivation. The responsibility of the university shifts therefore to that of finding academic staff who are sufficiently purposive and problem-centred to provide effective supervision to such students and to gain the respect of senior and highly qualified members of the sponsoring organizations.

SUBJECT/APPLICATION MATRICES

What follows is a theme with many variations and a wide range of possible titles and designations. Indeed, so great is the scope for confusion that it is necessary to concentrate on what appear to be academic essentials, ignoring detail which would only confuse. The fundamental idea is that students follow programmes of modules rigorously defined with respect to two axes. Several names can be attached to these. We will use 'subject' and 'applications'. The same axes are used to define the responsibilities of staff, although some members may, indeed should, function in both domains.

The 'subject groups' of staff normally have conventional academic labels, e.g. biology, urban sociology, systems analysis, fluid mechanics, theory of structures, etc. They are responsible for teaching and learning in the respective bodies of knowledge and technique. The modules they offer are available (at least in principle) to any degree programme within the school.

The 'applications groups', often led by members of staff whose orientation is professional rather than academic, are responsible for devising and supervising active learning through assignments – case studies, simulations, design exercises and major projects. These learning activities are designed to require the integration of the knowledge and technique learnt in the subject modules to which students have already been exposed, and to develop the general and transferable skills of problem-solving and independent study. The applications modules may bring together undergraduates of different degree programmes, deliberately to create the basis for inter-professional understanding and collaboration in later life. For this reason the supervising staff are mixed teams, similarly brought together for an interdisciplinary approach to real-world problems.

Students enrol in programmes having conventional designations (there are obvious reasons for preserving these). Under the control and counselling of programme co-ordinators they experience a designed sequence of subject and applications modules, normally involving a choice of modules in the more advanced years.

Each programme co-ordinator has the seniority to ensure that the selection and effectiveness of all modules in his or her programme meet the professional needs of the students in the programme. The programme co-ordinators, sitting together under the chairmanship of the director of studies or the head of school, design and revise the matrix of modules, draw up timetables and resolve clashes of priority as they arise.

The essential features of the model are:

No autonomous department exists to monopolize either the energies of staff or the time of the students.

Staff spend only part of their time with fellow-specialists. The remainder is spent with other colleagues in the devising and supervision of interdisciplinary problem-based activity. They are thereby forced into a continuous educational experience which matches that of the students.

The relevance and effectiveness of the subject modules are measured by the performance of the students in the applications modules.

The effectiveness of the applications modules is assessed by reference to professional societies, employers, former students and current students.

No one should underestimate the effort and determination required to introduce such a form of organization and to defend it until it reaches maturity. Some of the difficulties are, however, 'desirable difficulties'. That is to say, they are those which arise whenever faculty are required to leave the cosiness of academic specialties and justify their subjects to colleagues. Some members, for example, may be defensive and obstructive. Others may not be able to foresee the kind of specialist career they had promised themselves. Others, again, may not find it easy to accept the co-ordination which is necessary to ensure that modules are closely interrelated and that resources of all kinds are fully exploited. But some teachers may be excited by the possibilities opening before them and by the feeling that environmental education can be moved on to a higher and more effective level.

The last point is significant. It suggests that it may be easier to set up a scheme of this kind when a school is being created or when many new staff can be selected, at least partly, on the basis of their commitment to the scheme. Other opportunities may arise when new programmes are being designed. But even after a successful launch no complacency should be admitted. All experience in higher education shows that even the best beginnings offer no guarantee against creeping mediocrity. The price of excellence is eternal vigilance.

Conclusions

It is not easy briefly to summarize a discussion as wide-ranging as this, but conclusions which are not brief serve little purpose. The gist seems to be as follows:

The essential content of education is too often assumed to be factual information and specific technique rather than the processes whereby such knowledge is gathered and handled, and decisions are taken. It is the curriculum, not merely the syllabus, which determines the quality and value of environmental education.

The curriculum of students, overt and covert, is determined in large part by the ambience or culture among their teachers. In an important respect, the culture is the curriculum.

In the environmental education of engineers the attitudes of engineer teachers and the role and status of non-engineer teachers are major influences. It may be a truism that all organizations should take human factors into account, but in this field such factors are of crucial importance.

The role of research is also significant, but the traditional and narrow emphasis is inappropriate. The way forward lies in fostering an interdisciplinary learning-culture. Such an ambience is dependant on faculty organization and can show itself in many ways.

More models of academic organization exist than are generally recognized and considered. Simple and apparently inexpensive expedients like service teaching can be a waste of valuable human resources. More complex arrangements require detailed planning and close coordination.

The adoption of any form of organization should come from the critical discussion of the real aims of the school and not from accidental circumstances and unthinking conformity. If the structure is ill-chosen no level of excellence among faculty can overcome its defects.

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